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SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
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REPORT NO. SME-AB-3
25 July 1958

PANORAMIC CAMERA SYSTEM FOR A SPIN-STABILIZED SATELLITE

PART I
GENERAL DESIGN FACTORS

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PART I

GENERAL DESIGN FACTORS

ABSTRACT

Part I of Fairchild Report SME-AB-3 is introduced by a discussion of why a spin-stabilized satellite reconnaissance system is practical and represents an optimum for high information content of output.

This introduction is followed by a summary of studies made by Fairchild dealing with the general factors affecting the design of a panoramic type camera for a spin-stabilized satellite reconnaissance system.

Panoramic camera principles are reviewed briefly and the parameters of a panoramic camera system are related to the parameters of the spin-stabilized vehicle. The limitations imposed upon the system by the vehicle and the effect of operational requirements upon design are described.

The necessity of sensing and recording vehicle altitude during photography is discussed.

Considerable attention is paid to the optical and the emulsion characteristics necessary to achieve a high acuity photographic system. Particular stress is laid upon the problem of minimizing image motion on the film during exposure as a means of preserving the potential high acuity. A quantitative relationship between image motion and degradation of resolution is presented as extracted from one of the authoritative references consulted during this study.

A theoretical study of the effects of spin axis "wobble" on image blur and on photogrammetry was conducted as a special effort in this part of the program. The study report is presented as Appendix I. Also an experimental study of the special problems arising from recovery of the film package from the sea is presented in report form as Appendix 2.

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INTRODUCTION

After careful study of all the problems related to the satellite reconnaissance program Fairchild Camera and Instrument Corporation has concluded that the spin-stabilized reconnaissance vehicle offers the best advantages from the standpoint of end product information content. This conclusion is in line with a Rand Corporation Report on Spin Stabilized Satellite Reconnaissance and is reached with a knowledge of the General Electric Company's success with re-entry capsules and with a knowledge of the status of Lockheed's missile program. Fairchild's confidence in the success of the program is confirmed by the Rand Corporation report. In fact, Fairchild's study concurs with the basic parameters established in the Rand Report and justifies them from the practical aspect in generating the detailed parameters required for an actual operational system.

Some of the considerations in arriving at this conclusion are as follows:

a) The spin-stablized vehicle permits lower altitude orbits than the vertical stabilized unit. This obviously means more information from the spin-stabilized system since the scale is larger. (For every 10 miles of increase in altitude, the size of ground detail resolved gets poorer by about one additional foot.)

b) Since the spin-stabilized vehicle can operate at lower altitude, this vehicle can carry more payload weight than the higher altitude vertical stabilized unit. Meetings with the Lockheed Missile Systems Division indicated the critical nature of weight and the important weight-altitude relationship.

c) The spin-stabilized approach offers the most efficient utilization of the weight and space allowance for a camera package. Additionally it offers the most convenient arrangement for properly locating the recoverable capsule both from the standpoint of film path and mechanism reliability and of proper orientation for recovery.

Because of the possibility of capitalizing on the spin of the vehicle to rotate the optical axis in space a spin-stabilized vehicle lends itself ideally to panoramic photography. This is a field in which Fairchild has acquired considerable experience.

The philosophy of this study has been to consider the short time required for an operational mission as the primary objective and to make parameter trade-offs consistent with this time requirement and still provide the data required. The Rand Corporation Report has accomplished much in this direction.

Having made the decision that a panoramic camera in a spin-stabilized vehicle is an efficient satellite reconnaissance system, it is logical to conduct an analysis of the problem to determine the major factors to be considered in the design of the camera. This report attempts to do this quite completely. Part I of SME-AB-3 treats the engineering analysis of parameters starting with the operational requirements and reaching conclusions as to the design criteria for the program.

Since any high acuity photographic system must be based necessarily on the use of a film that will not limit the performance some extra attention seems justified. It appears logical to analyze the problem sufficiently well in a broad sense to be able to make fairly positive recommendations on the film to be used.

Part I of Fairchild Report SME-AB-3 is entitled "General Design Factors". In this portion of the report the factors to be considered are analyzed. This analysis leads logically to the general design of the camera system which is the subject of Part II of the report.

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ANALYSIS OF GENERAL DESIGN FACTORS

A. Application of the Panoramic Principle to Photographic Reconnaissance from a Spin-Stabilized Vehicle

A spin stabilized vehicle lends itself ideally to panoramic photography, a field in wich Fairchild has recently acquired considerable experience. In this application, the camera design problems are reduced to a minimum since the vehicle provides the all important scanning with the lens. The camera need only move the film past the exposure slit in synchronism with the image motion during photography. It would be well, in this introduction, to discuss briefly the panoramic principle to be employed in this study.

Basically, when a camera scans an object by physically rotating it with no shutter in the unit, the images of the object at the focal plane will smear across the format at the velocity V equal to the angular rate of scanning times the lens focal length as a lever arm. Expressed mathematically:

$$V = wF \qquad (1)$$

where w = angular scan rate (radians/sec)
F = lens focal length (inches)
V = image velocity across focal plane (inches/sec)

To avoid this smearing it is necessary to move the film at the same velocity V as the image. There is one additional requirement, however, and that is, to avoid excessive exposure, since image and film are synchronized indefinitely, to provide a slit with a width that would produce the required exposure time. This slit width is determined simply by the velocity of the film and the desired exposure time. Again expressed mathematically:

$$W = Vt \qquad (2)$$

where W = slit width (inches)
V = film or image velocity (incles/sec)
t = exposure time (seconds)

Equations (1) and (2), then, make up the total fundamental expressions for designing a panoramic camera. The images of the object scanned are "painted" on the film through the narrow slit as the film moves past it. No shutter is required in this type of camera since the slit width determines the exposure time. The ensuing study report will treat actual values for the operational conditions.

B. <u>General System Parameters</u>

1. <u>Operational Requirements of the Specific Vehicle-Reconnaissance System</u>

Fairchild's contacts with the Lockheed Missile Systems Division and the Rand Corporation provided the knowledge of the basic operational requirements for the mission under study. The fundamental requirement is to photograph the target area from an orbiting satellite and recover the film for intelligence purposes. In line with this fundamental requirement the following operational parameters have been established:

a. Operational mission to be successfully accomplished within six to eight months from go-ahead.

b. A passive spin-stabilized reconnaissance pod is to be used for the satellite.

c. A re-entry capsule shall be used containing the exposed film for recovery.

d. The total pod weight including the data capsule and re-entry rocket shall not exceed 300 pounds.

e. The vehicle speed = 25,000 ft/sec = 4 minutes of arc/second oriented as a polar orbit around the earth.

f. The vehicle altitude = 135 statute miles for camera parameter considerations.

g. Vehicle acceleration - 10 g's launch.

h. Vehicle power supply - 28 volts D.C.(Battery Supply)

i. Environmental Conditions

1) Camera Operation

   a) Temperature range = +40°F to +120°F
   b) Pressurized Pod = 1 atmosphere maximum to 1/3 atmosphere minimum
   c) Vehicle movements = due to camera reactions - camera reactions to be kept to an absolute minimum.

2) Recoverable Cassette

   a) Operational environments - same as camera
   b) Re-entry environments - 4000g's shock for two to three milliseconds.

2. Photographic Design Objectives

   a. Provide 36 minutes of active photography covering approximately 300 statute miles of swarth width with approximately ten percent overlap along the line of flight.

   b. Resolution requirement - detect an object on the ground of approximately 10 feet.

   c. Photography to be taken at all times of the year at latitudes from approximately 45° North Latitude to 75° North Latitude.

   d. Provide necessary data to permit location of ground points to a design objective of ±1 mile.

3. Basic Parameters Established for the Photographic System by the Vehicle and the Operational Requirements

Perhaps the single most important limitation in selecting camera parameters for a reconnaissance system is the weight and space limitation established. The Rand Report established or derived most of the following basic parameters. Fairchild's study of these parameters in conjunction with a study of light levels and scale factor considerations have resulted in the selection of a 24 inch lens instead of a 12 inch lens as recommended in the Rand Report. This subject is covered more completely in subsequent sections.

Basic Design Parameters

a. Maximum Camera Weight (including 13 pounds of film) = 60 lbs.

b. Maximum Take-up Cassette Weight = 9 lbs. empty.

c. Lens focal length = 24 inches.

d. Film width = 5 inch film.

e. Transverse angular coverage (derived from ground swath width requirement of 300 statute miles) = approximately 93°.

f. Vehicle Spin Speed = approximately 25.0 rpm. (This value is analyzed more fully in this study report).

g. Vehicle Wobble to be kept to a minimum. (A wobble study is included in the appendix of this report).

A brief discussion of the basic design parameters itemized above is in order at this time. Since all remaining parameters in this study report hinge on the above values, it is important to justify them in order to assure a firm foundation for the subsequent study.

A picture of the weight breakdown is approximately as follows:

Pod Structure	=	22 lbs.
Beacon & Antenna	=	30 lbs.
Telemetering	=	10 lbs.
Battery Support	=	6 lbs.
Batteries	=	29 lbs.
Environmental Control	=	10 lbs.
Capsule & Cassette (with film)	=	109 lbs.
Re-entry Rocket	=	36 lbs.
Camera System	=	47 lbs.
Total Weight	=	299 lbs.

The limitation of film capacity is brought about due to system weight and the size of the re-entry capsule which is fully developed. Hence the largest standard film width that could be considered was 5 inch wide film. The total film capacity was then established in accordance with the ground coverage requirements to be approximately 1500 ft. for a 24" focal length lens. This capacity results in a roll of film of about 9 inches in diameter. Since a cassette had to be provided to enclose this roll of film for recovery, this size and weight was considered maximum for the 16-1/2 inch inside diameter re-entry sphere.

The other basic design parameters spelled out will be covered more thoroughly in the subsequent sections of this preliminary study report.

C. <u>Derivation of Camera Cycling Rate, Film Transport Rate and Slit Width from Basic Parameters</u>

As outlined in Part I Section B, a 24 inch focal length lens and a 5 inch film have been selected. The width of the panoramic photograph is therefore 4-1/2 inches wide and the angular coverage of the lens in the flight direction is 10° 44'. In order to insure a minimum 10% overlap of ground coverage at vertical, the minimum altitude is used in conjunction with the vehicle speed to determine the cycling rate of the camera. The minimum altitude is assumed to be 135 statute miles which is equivalent to 713,000 feet. At this minimum altitude the lens will cover a distance of 133,584 feet or 25.3 statute miles on the ground in the direction of vehicle motion. For 10% overlap a photograph must be taken every time the vehicle covers a distance of 133,584 feet minus 10% or 120,226 feet. For a vehicle forward velocity of 25,000 feet/sec., the time required to travel 120,226 feet is 4.8 sec. In other words the cycling rate of the camera has to be at least 1/4.8 exposures per second.

Since the cycling rate of the panoramic camera is related to the scan velocity and scan velocity in turn is related to the rotational spin rate of the vehicle, not more than one exposure can be taken during one revolution of the vehicle. This relationship would establish 1/4.8 = 0.208 rev/sec as the minimum rotational spin of the vehicle. If a higher spin rate of the vehicle is selected, it has to be a multiple of 0.208 rev/sec and an exposure will be still taken at intervals of 4.8 seconds.

In order to select a vehicle spin rate most favorable for the camera operation, reference is made to the equations (1) and (2).

film velocity: $V = WF$ (in/sec); where: W = angular scan velocity (rad/sec)

exposure time: $t = \frac{W}{V}$ (sec) F = focal length of the lens (in.)

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V = image velocity across focal plane (inches/sec)
W = width of exposure slit (in.)
t = exposure time (secs.)

For the camera under study the camera scan velocity and the vehicle spin rate are equal. Therefore, for a spin rate of .208 rev/sec the scan velocity is: W = .208 x 2 = 1.306 rad/sec.; the film velocity is; V = 1.306 x 24 = 31.34 in/sec; and the width of the exposure slit for an exposure time of t = 1/4000 sec. becomes W = Vt = 31.34/4000 = .00784 inches. Such a narrow exposure slit is obviously not practical, since a variation of the slit by .001 inches would result in an exposure error of 12%. Since it can also be assumed that a spin rate of only 1/5 rev/sec will present stabilization problems, a faster spin rate is preferred.

Faster spin rates will increase the exposure slit width for a given exposure time, reducing the tolerance problem, increase the efficiency of shutter and decrease the danger of "banding". But faster spin rates will also magnify the problem of film synchronization, since the equation V=WF has to be satisfied. The film is driven across the exposure slit by a servo motor. Any error in the film velocity "V" will result in a relative displacement between image and film and create a "blur" reducing the resolution of the photograph. If it is assumed that the camera film drive system will move the film with a velocity within 1% of the required velocity WF, the resulting "blur" will be proportional to the spin rate "W". In other words a higher spin rate will result in more degradation of the photograph due to "blur" if the film drive error is assumed to be a constant percentage of the film speed.

Thus, a compromise between the two conflicting requirements of low spin rate preferred for film synchronization and high spin rate preferred for exposure slit consideration has to be found. This compromise must also consider the important system consideration of spin stabilization of the vehicle.

At present it is felt, that a spin rate in the order of 25 rpm which is in excess of the 18 rpm recommended in the Rand Report, is an excellent compromise. The camera will take a photograph every second revolution. This will result in an actual spin speed of 25 rpm to give exposures every 4.8 sec. with a resulting overlap of 10%.

The film velocity is then:

$$V = WF = \frac{25 \text{ rpm}}{60} \times 2 \quad \times 24 = 62.8 \text{ inches/second.}$$

For an exposure time at 1/1000 sec. a velocity error of 0.5% will produce a blur of $\frac{62.8}{200 \times 1000} = .000314$ inches.

Referring to curve drawing 951L52 such a "blur" will reduce the resolution of the photograph from 100 lines/mm to approximately 95 lines/mm. At faster shutter speeds the "blur" will be proportionately reduced, but "blur" caused by other conditions (as described in other sections of this report) has to be added to one produced by the film velocity synchronization error.

As recommended in the Rand Report the scan angle of the camera has been set at 93°. This angle will produce a transverse ground coverage of approximately 285 statute miles for minimum altitude. The scan time at a spin rate of 25 rpm is .62 seconds. During this time, since a 24-inch focal length lens is used, 39.0 inches of active format length of film is exposed at a rate of 62.8 inches/sec.

D. Derivation of Image Motion Compensation Requirements From Basic Parameters

The forward motion of the vehicle will produce an image motion in the focal plane. The general equation for this image motion is:

$$I.M. = \frac{V}{H} F \text{ (inches)} \quad (3)$$

where V = forward velocity of vehicle (ft/sec)
H = altitude of vehicle (ft)
F = focal length of lens (inches)

In the panoramic camera "H" varies with the scan angle and the equation reads:

$$I.M. = \frac{V}{H} \cdot F \cdot \cos \quad (4)$$

where = scan angle measured from the vertical (degrees).

For a minimum altitude of 713,000 feet, a velocity of 25,000 ft/sec and a scan angle of 0°.

$$I.M. = \frac{25{,}000}{713{,}000} \times 24 = 0.84 \text{ inches/sec.}$$

Such an image motion will produce a "blur" of .00084 inches over an exposure time of 1/1000 sec. At a scan angle = 46.5° the blur will decrease to .00059 inches.

E. Discussion of Attitude Sensing and Recording Requirements

Several means of establishing the true vertical have been investigated. It was felt during these investigations that while the establishing of the vertical and the vehicle attitude in the direction of spin was extremely important, the establishing of the vertical in the direction of the forward motion was only of secondary importance. This approach was based on the fact, that an accurate recording of true vertical during the exposure scan is required for any photogrammetric calculation of the scale factor of the photograph, with the zero point of the system coinciding with the nadir point and the Y and y axis in the direction of flight, and X and x perpendicular to it, then the scale factors of a panoramic photograph become:

$$\frac{x}{X} = \frac{x}{H} \cot \frac{x}{F} ; \qquad \frac{dx}{dX} = \frac{F}{H} \cdot \frac{1}{\mathrm{Sec}^2 \frac{x}{F}} \tag{5}$$

$$\frac{y}{Y} = \frac{F}{H} \cos \frac{x}{F} ; \qquad \frac{dy}{dY} = \frac{F}{H} \cos \frac{x}{F} \tag{6}$$

From the above equation it is evident that the establishing of a true "x" is of great importance, while an error in the "y" value will result in only a minor error in establishing ground distances.

The sensing of attitude in the direction transverse to the flight axis will facilitate the triggering of the film transport mechanism, since this triggering has to occur 46.5° from the vertical.

F. Resolution and Exposure Considerations

1. General

The resolution requirements and exposure necessary in a reconnaissance camera are closely allied functions. Invariably, the parameters selected must be a compromise to give the best overall system efficiency rather than being able to choose the optimum condition for each requirement. Since image motion exists due to vehicle motion and scanning operations and compensation for all these undesirable motions is complex and at best only partially compensated for relatively short exposure times are necessary to limit the smear or blurring of the image during exposure.

With given light conditions of aerial photography, a relatively short exposure time demands a large aperture lens and/or high speed film emulsions. Unfortunately, both large aperture lens and high speed film emulsion parameters lead in a direction of reduced resolution capability. Specifically in the case of this program where the delivery time for the hardware prohibits new developments in lenses and film emulsions, it is necessary to select the best known components available to arrive at the best overall results.

2. Exposure Factors

In determining the required exposures for the Panoramic camera, several factors must be taken into consideration. Among the most important are scene brightness and brightness ratio at the camera, spectral distribution of image forming light, film speed, film spectral sensitivity, film quality capability, shutter speed, aperture, film processing, time of day, month and cloud cover.

For convenience, each major factor is considered separately prior to the discussion of the interdependence of these factors.

a, Brightness

Scene brightness on the ground is calculated from standard equations and from experimental data.* Scene brightness includes both direct illumination and sky light in the horizontal plane. Based on the best data available to this organization, assumed average values of 0.1 for atmospheric reflectivity (no cloud cover), 0.9 for atmospheric transmissivity and 0.2 for ground reflectivity were then used to complete the calculation of scene brightness of a ground target from above the atmosphere observed. Drawing 951L39 presents this data plotted as a function of solar altitude.

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* 1) Smithsonian Physical Tables, 9th Revised Edition and
2) Smithsonian Meterological Tables, 6th Revised Edition.

b. Scene Brightness Ratio

Drawing 951L39 indicates only the actual brightness available at the camera. The amount of information available on the film is, however, also a function of the brightness ratio of the image forming light. As we consider decreasing solar altitudes, an increasing percentage of the light reaching the camera is from atmospheric reflection. This adds an increasing uniform illumination to the ground target light thus lowering the apparent target brightness ratio. The decrease in target contrast with increasing percentage of sky light (decreasing solar altitude) is indicated in Drawing 951L40 where target contrast is plotted as a function of solar altitude for (1) the case of a black target against an average ground background of reflectivity 0.2 and for (2) the extreme case of a black target against snow with a reflectivity of 0.9.

c. Spectral Distribution of Image Forming Light

With decreasing solar altitudes, the percentage of total scene illumination contributed by sky light increases as indicated in Drawing 951L41. At very low and decreasing solar altitudes the spectrum of the direct illumination shifts rapidly towards the red while sky light is still predominately in the blue region. These factors allow the choice of several techniques for obtaining photographic information at low solar altitudes. First, use of a minus blue filter will increase scene contrast by eliminating a large portion of sky light reflected by the atmosphere and simultaneously lower the exposing brightness of shadow areas while essentially maintaining the exposing brightness of highlights. However, elimination of sky light will both increase the required exposure and greatly decrease, if not eliminate, shadow detail. In the second case, omitting color filters will allow recording both highlight and shadow detail, but will result in extremely low target brightness ratios at the camera. Finally, infinite number of scene contrasts between these two extremes can be obtained by choice of the degree of blue light filtering.

d. Film Characteristics

1) Spectral Sensitivities

All films that can be favorably considered for use in the Panoramic camera on the basis of speed, quality, and availability have completely adequate spectral sensitivity characteristics.

2) Quality and Speed

At any given time in the state-of-the-art of silver halide sensitization, image quality capability varies as some inverse function of film speed. This fact immediately presents a balance between film quality and speed that must be made in the choice of a suitable emulsion since it is necessary to obtain both high quality images and the longest possible operational day. At one extreme, ultra-high speed emulsions have relatively low inherent contrasts, a characteristic incompatible with the necessity for obtaining high quantities of information from medium contrast targets. The relatively low resolution and acutance, and high granularity of these materials contribute significant degradation of information quality to the lens-film system (for the quality capabilities of the chosen lenses). At the other extreme, choice of ultra-high quality emulsions results in a lens-film quality that is lens limited, and, the inherent high contrast of these low speed - high quality materials will increase the resultant image contrast of medium contrast targets. However, as the illumination level decreases a point is reached where exposure times must be increased to obtain proper film exposure and image quality will decrease rapidly as a result of increasing image motion, resulting in a shortened operational day.

(It is assumed that exposures will be chosen to give emulsion densities yielding the highest overall quality possible for the given brightness range and emulsion.)

3. Computation of System Quality as a Function of Length of Operational Day

a) Scene Brightness at Various Locations and Times

For a given day, time and geographical location, film exposing brightness is computed using equation (7) to determine solar altitude and Drawing 951L39 to determine scene brightness at this solar Altitude.

$$\sin\alpha = \sin\lambda \cdot \sin\delta + \cos\lambda \cdot \cos\delta \cdot \cos 15t \qquad (7)$$

where: α is the solar altitude in degrees.
λ is the latitude (North).
t is the time in hours from noon. (local)
δ is the declination where $\sin\delta = \sin T \sin 23.5°$.
T is in days with March 21 = 0.

Drawing 951L42 presents scene brightness above the atmosphere of ground targets as a function of time of day for three latitudes at the two extremes of declination (±23.5°).

b) Brightness required for Given Exposure Time and Lens-Film Combination

Calculation of scene brightness required for a given exposure time was made utilizing equation (8).

$$B = \frac{K.C.T^2}{t.S_W} \qquad (8)$$

where: B = Scene Brightness (foot-lamberts)
K = Constant defining working density on film negative (0.5)
C = Filter factor (transmission reduction) (2.0)
t = Effective exposure time (sec.)
S_W = Emulsion sensitivity rating (Weston speed)
T = T Stop number (4.3)

In all calculations, film speed criteria are chosen so as to place the various scene brightnesses on the film in a manner that will allow maximum utilization of inherent film resolution (which is a function of exposure and film processing) and that will result in a minimum of 1 stop exposure latitude for the given scene brightness ratio.

These data are plotted in Drawing 951L44.

c) Resolution Degradation Resulting from Image Motion

Experimental work in connection with varying amounts of relative motion (motion between film and image) have been performed (Romer[1] and Gregory[2]) showing the degradation in resolution with motion.

These experiments were carried out with actual lens-film-camera combinations and with precisely controlled motion being introduced to observe the degradation. These data are plotted in Drawing 951L52.

Using synchronization errors of 0.22 inches per second and forward motion compensation error of 0.09 inches per second, the vector sum image motion for various exposure times is plotted in Drawing 951L53. *

Using Drawings 951L52 and 951L53, resolution degradation resulting from image motion for a given emulsion, used with the proposed system, can be readily determined.

d) Consolidation of Data for Determination of System Resolution as a Function of Length of Photographic Day

Drawings 951L54, 951L55 and 951L56 present system resolution as a function of length of photographic day for three different latitudes during two days, one representing the maximum scene brightness the other representing the minimum scene brightness available during the year.

Using the criteria chosen for obtaining the calculations presented in Drawing 951L44, major decreases in system resolution will not appear until image motion becomes appreciable. Resolution degradation, appearing as target contrast decreases, have been compensated for by contrast control during film processing to the greatest extent possible for the given emulsion. After maximum useable contrast has been attained resolution decreases rapidly with decreasing target contrast.

* 1) "Suppression of Image Movement in Air Photography" - W. Romer, D.Techn. Sc., Poland, F. Inst. P., F.R.P.S.Royal Aircraft Establishment, Farnsborough, Hants, England.
2) "Interim Reports on the Effect of Image Movement on the Definition of Air Photographs" - J.M. Gregory, Kodak Research Labs; Harrow, England, AT1165074, F52-2-1947 Reel C-6723.

G. Recommendations As to Film Emulsion

1. General Discussion

a) Choice of "Best" Emulsion

Choice of "best" emulsion for this system is, in the ideal case, a simple matter of determining the emulsion that results in the highest quality image for the longest operational day (time during which photography of the given quality is possible). However, in the actual case, many factors which are not completely reducible to quantitative relationships are important in overall system analysis. Additionally, no completely satisfactory technique exists for quantitatively measuring system quality (by "quality" it is meant the magnitude of usable information density that can be obtained from the final product). Although quality is also a function of such film and/or lens characteristics as acutance and granularity, comparisons are made solely on the basis of resolution. Considering the accuracy of data and assumptions required for the succeeding calculations, resolution is probably an adequate criterion of system quality.

b) Super XX vs. Aerecon Plus X

From Drawings 951L54, 951L55 and 951L56 it can be seen that for any specified time of year, latitude, and length of photographic day Aerecon Plus X is superior to Super XX in terms of lens-film-processing resolution.

In addition to this advantage in resolution, several distinctive characteristics of Aerecon Plus X not considered in the foregoing analysis are extremely advantageous when used in the proposed system. Aerecon Plus X has an acutance capability that is superior to Super XX and maintains this capability even at realtively high densities. Aerecon Plus X also lends itself to automatic contrast control at constant exposure speed or to speed control at constant contrast during processing far better than any other emulsion now commercially available.

c) Aerecon Plus X vs. SO-1213

Neglecting considerations of the length of photographic day, use of SO-1213 results in a far greater maximum lens-film-processing resolution than Aerecon Plus X. Along with superior resolution, SO-1213 exhibits acutance and contrast characteristics significantly higher than Aerecon Plus X. The only limitations of SO-1213 are its relatively low sensitivity (speed) and that although the inherently high contrast of SO-1213 would allow the use of forced developing techniques to increase exposure speed, this would still not result in an exposure speed comparable to that which could be obtained with Aerecon Plus X without destroying its higher image quality capability. Finally, SO-1213 does not have the desirable characteristics of Aerecon Plus X that result in the wide range of the proeessing control discussed in the previous section.

Since the total misssion length is somewhat limited and the possibility exists of using different films at different times of the year, it is recommended that SO-1213 be used when the length of photographic day using SO-1213 is sufficient to satisfy operational requirements. This will result in the maximum image quality. However, for several winter months at latitudes greater than 65°, SO-1213 does not have sufficient sensitivity to obtain images at exposure times where SO-1213 still has a resolution superior to Aerecon Plus X. During these periods, it is recommended that Aerecon Plus X be used (See Drawings 951L57 and 951L58 for plots of SO-1213 resolution as functions of time of year and latitude).

d) Specific Recommendations

1) Aerecon Plus X is superior to Super XX in every respect. It is therefore recommended that Super XX not be used in this system.

2) It is recommended that SO-1213 be used during those times of the year when its use results in a photographic day of sufficient length to satisfy operational requirements during the entire mission (this will be for the major portion of the solar year).

3) At all other times it is recommended that Aerecon Plus X be used.

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H. Special Problems

During the course of this investigation it has become necessary to conduct studies of two subjects which arehighly specialized, but yet closely related to the basic study. In fact the outcome of these studies may be very important in deciding upon the approach to design of the whole system and certain subsystems within it. In the one case it seemed desirable to investigate the limitations imposed upon the photographic system by instability in the satellite vehicle caused by deviation of the spin axis from the axis of least moment of inertia. This "wobble" can result in degradation of resolution through image motion blur. It can also interfere with accurate target location. Accordingly a study was conducted and the results reported under the title of Effect of Non-Coincidence of the Spin Axis and the (Minimum) Principal Axis of Inertia on Blur and Photogrammetry. This report forms Appendix 1 of Part 1.

In the second problem it was necessary to resort to experimentation. This probelm was to determine the effects of salt water and dye solution on exposed photographic film. The importance of this matter to the satellite reconnaissance system lies in the plan of recovery of data which depends upon landing the recoverable film package in the sea. The results of the experimentation are reported in Appendix 2 entitled, Effects on Photographic Film Resulting From Immersion in Salt Water and Salt Water Plus Yellow Dye Marker.

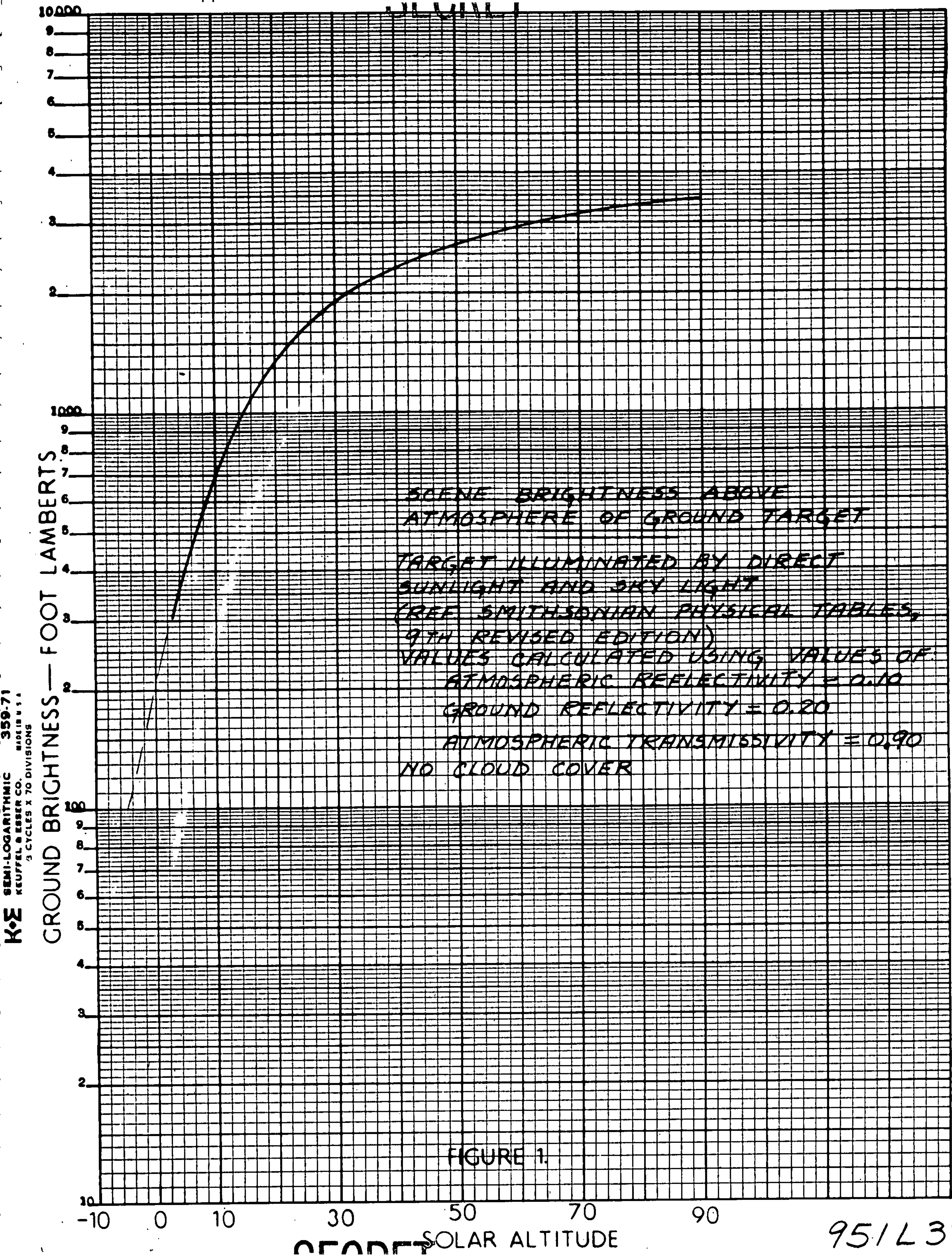

FIGURE 1.

951L39

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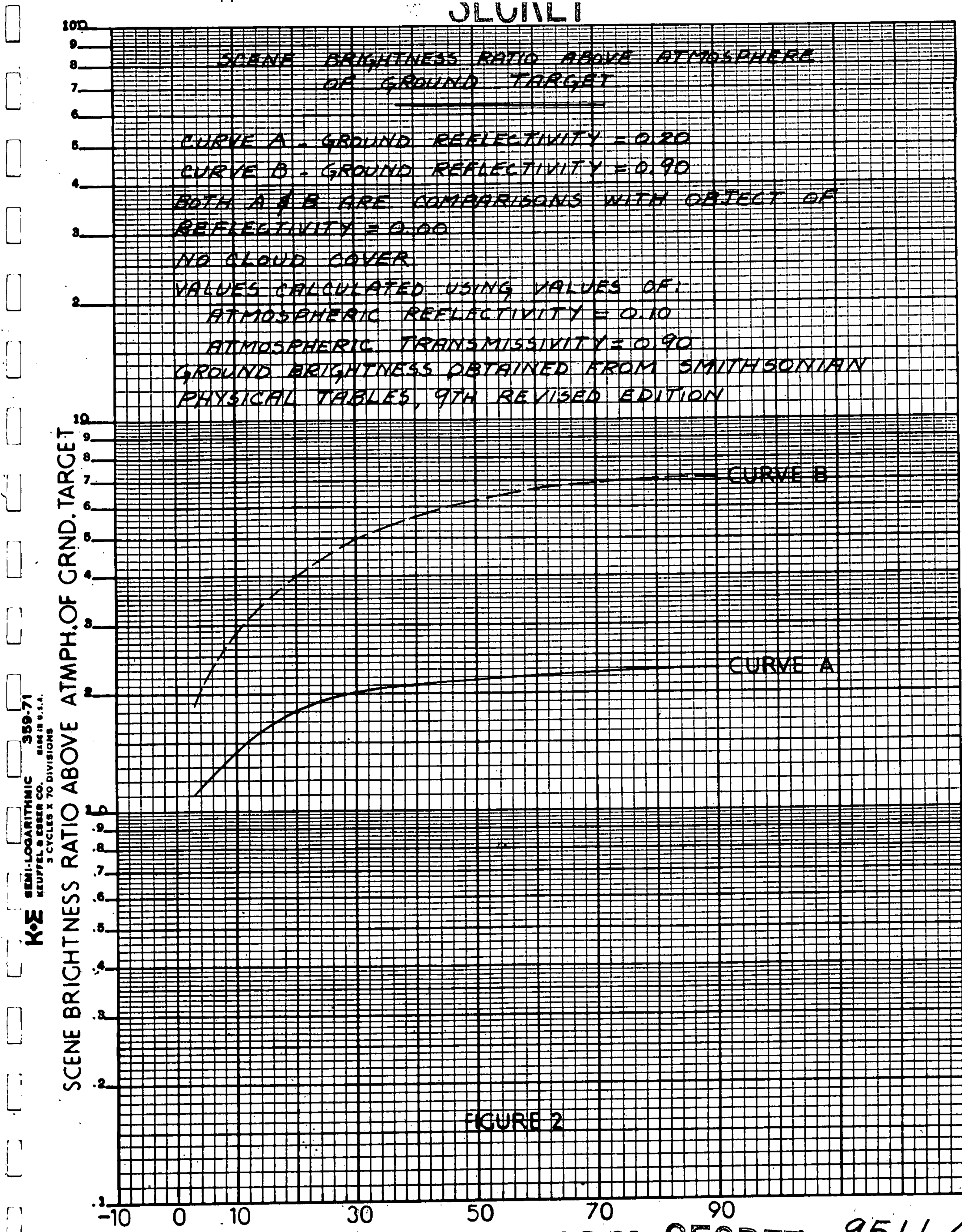

FIGURE 2

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951L40

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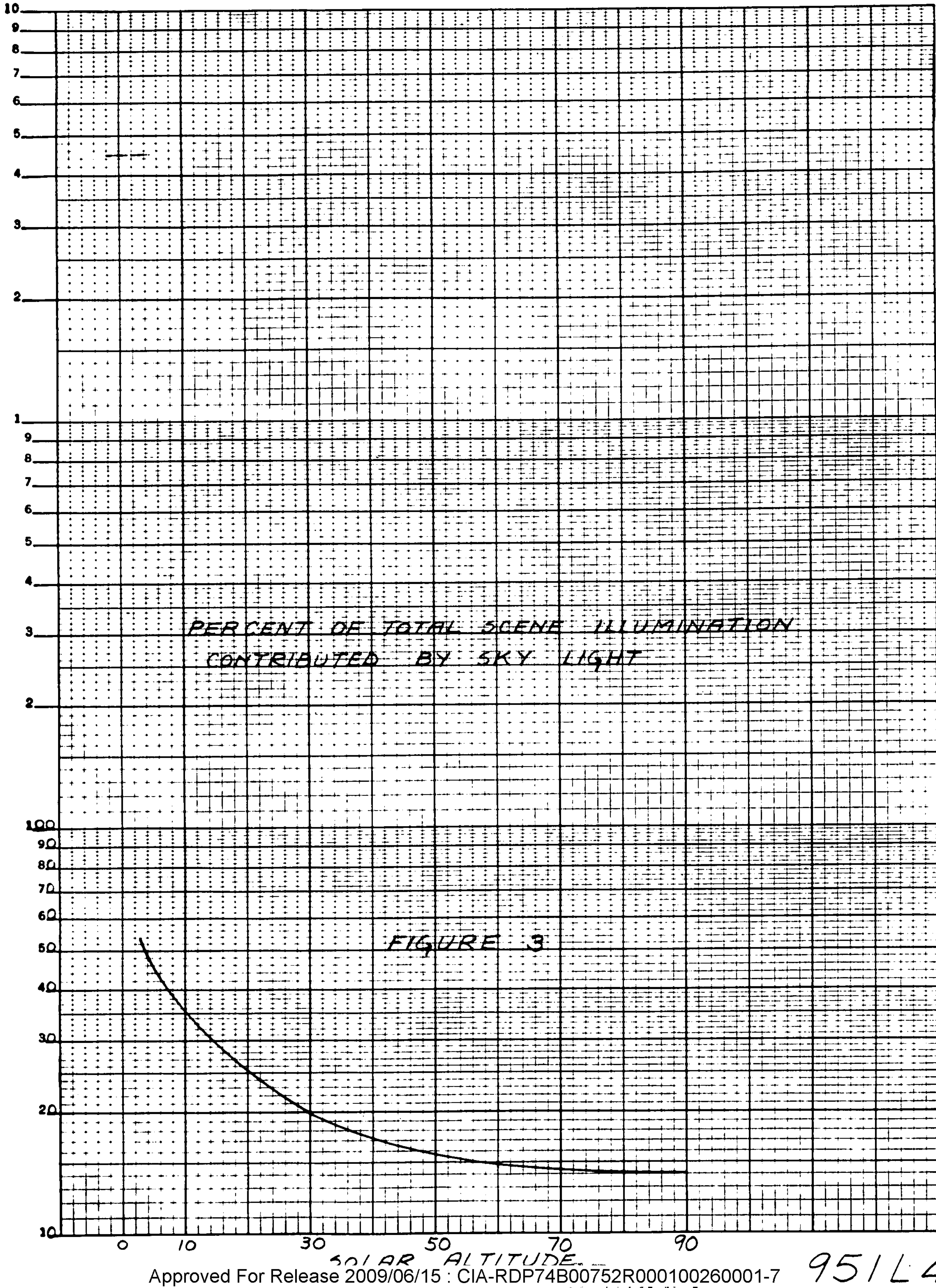
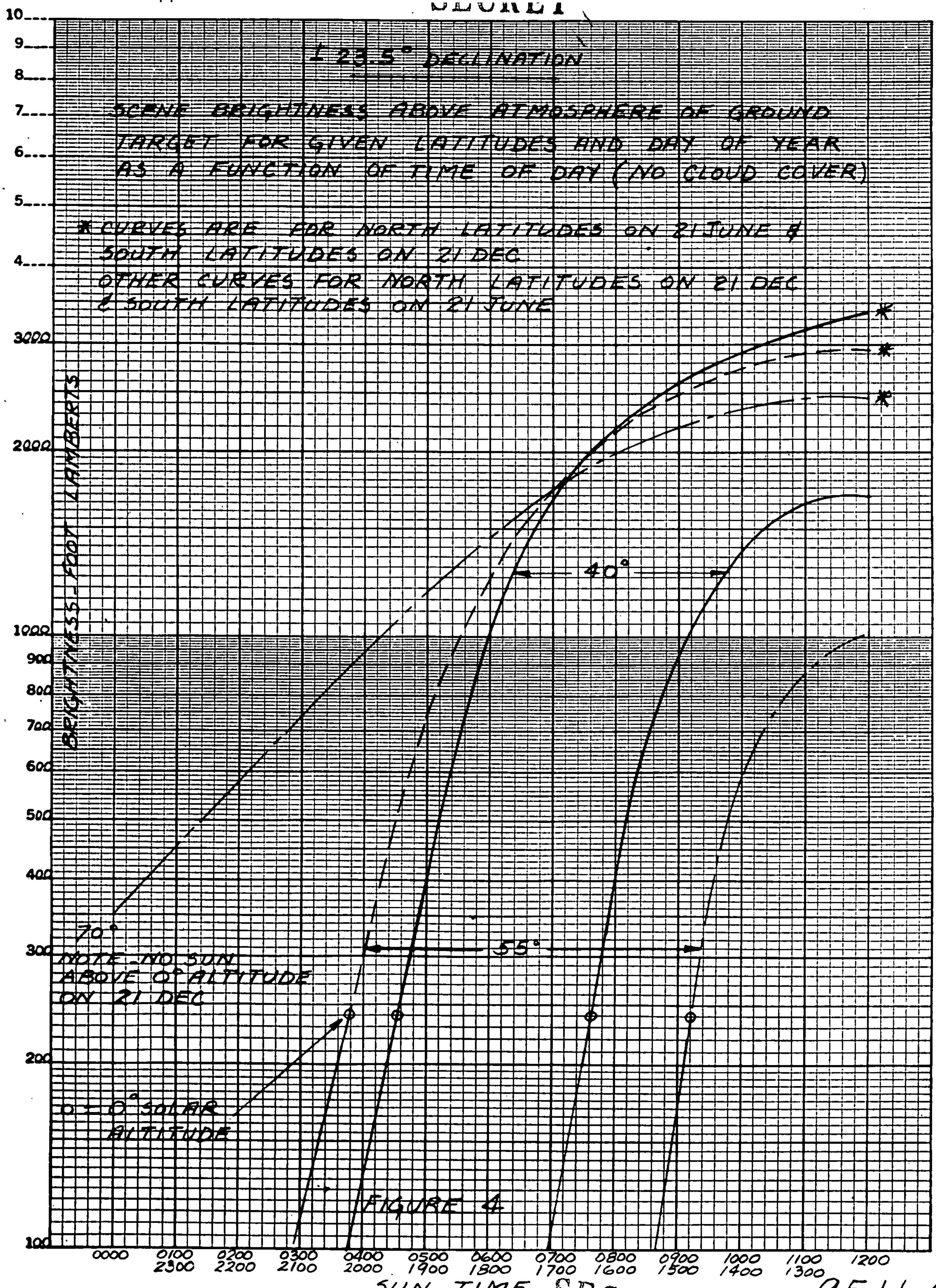


95/L41



K&E SEMI-LOGARITHMIC 359-61 KEUFFEL & ESSER CO. MADE IN U.S.A. 2 CYCLES X 70 DIVISIONS

951L42

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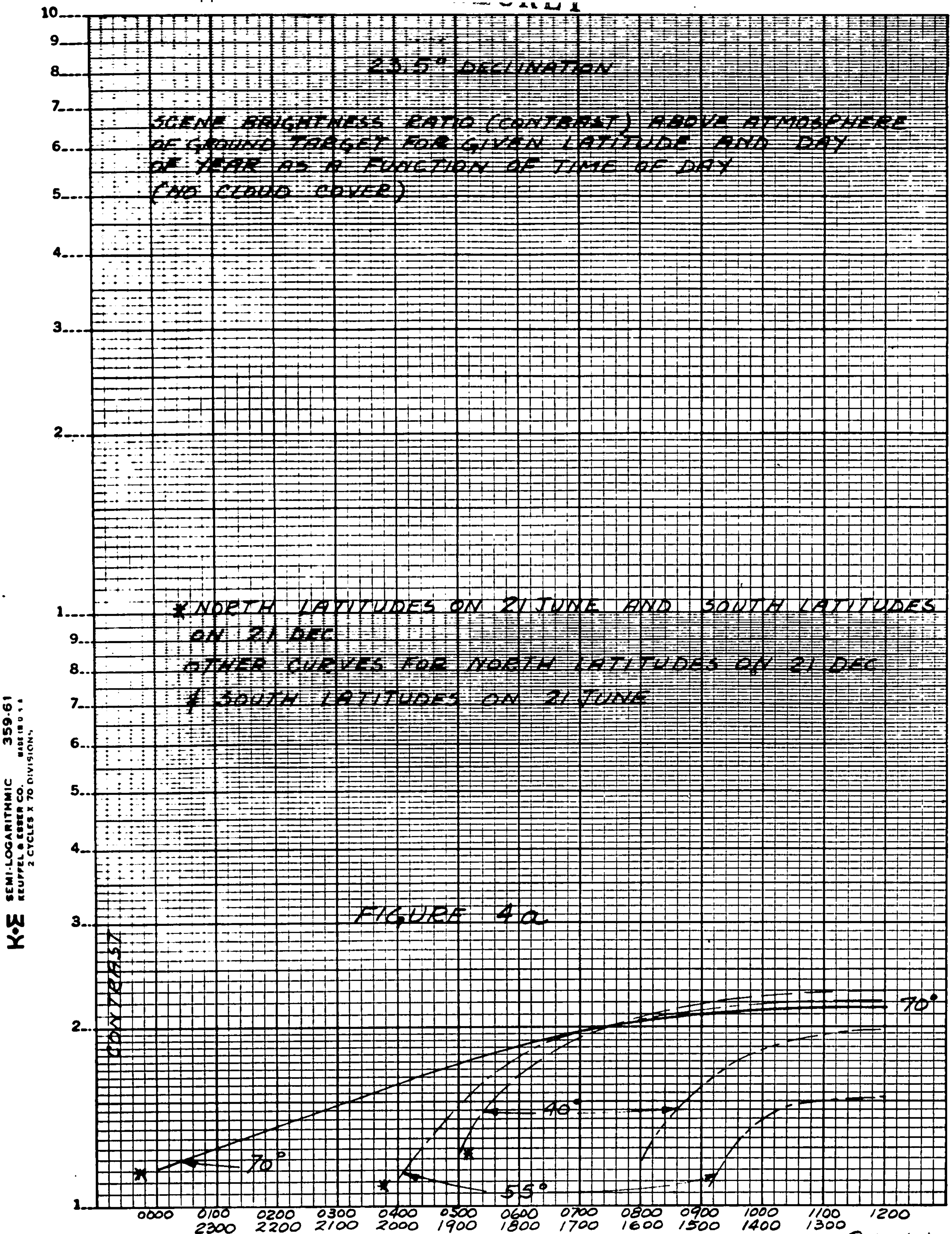

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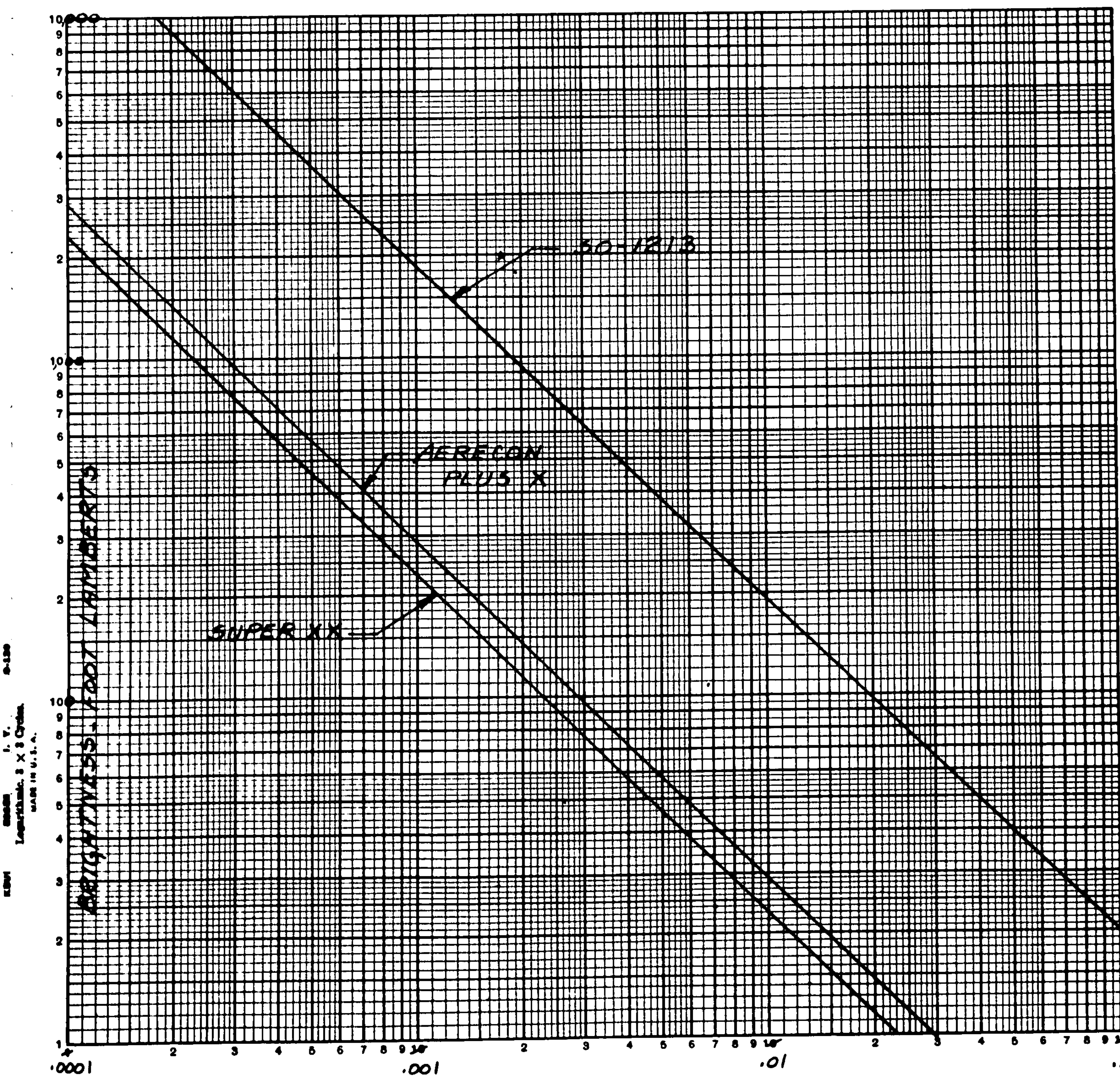

FIGURE 5

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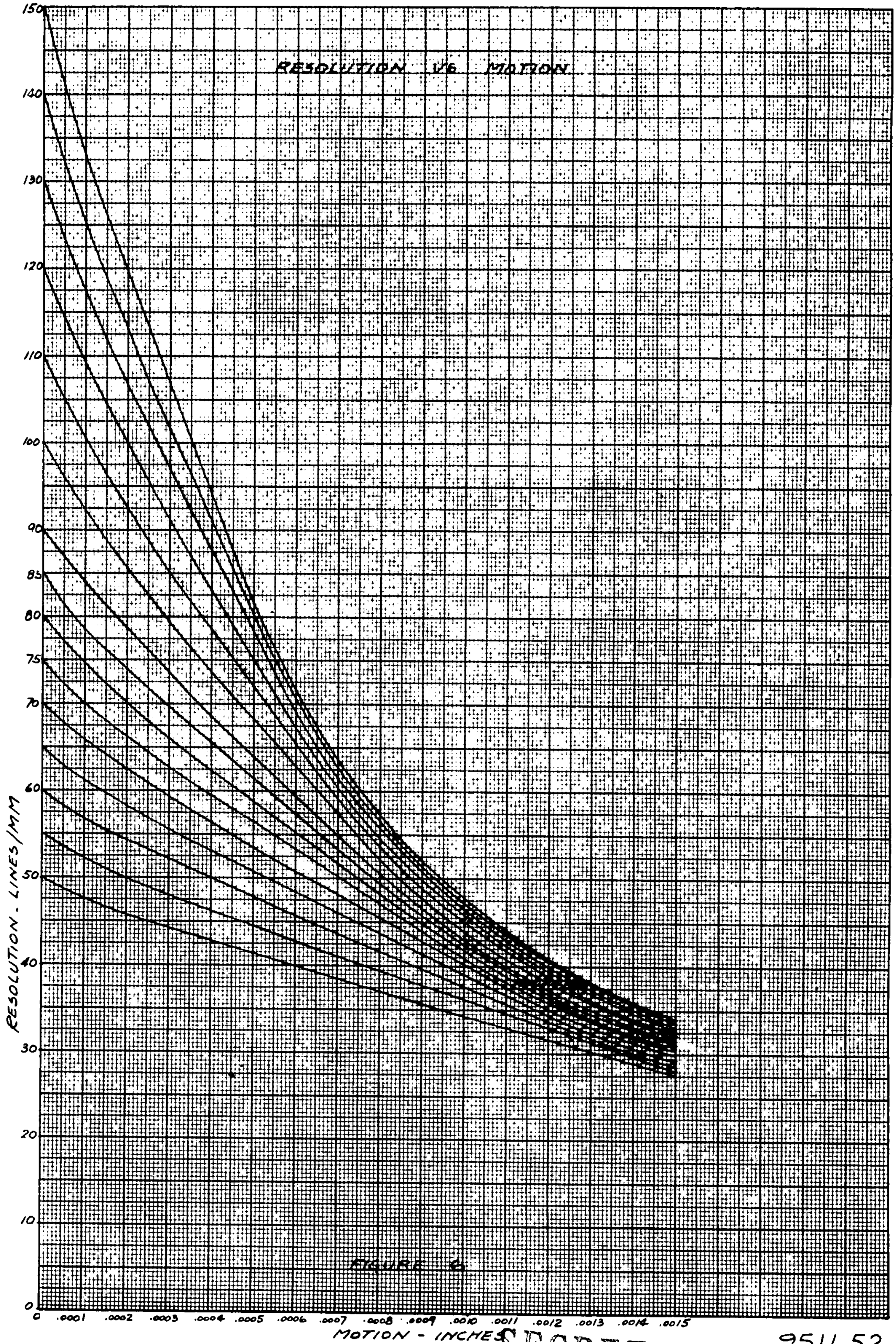

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951L52

ASSUMING SYNC ERROR = 0.31 IN/SEC
FMC ERROR = 0.0129 IN/SEC
(24" LENS)

— IMAGE MOTION VS EXPOSURE TIME

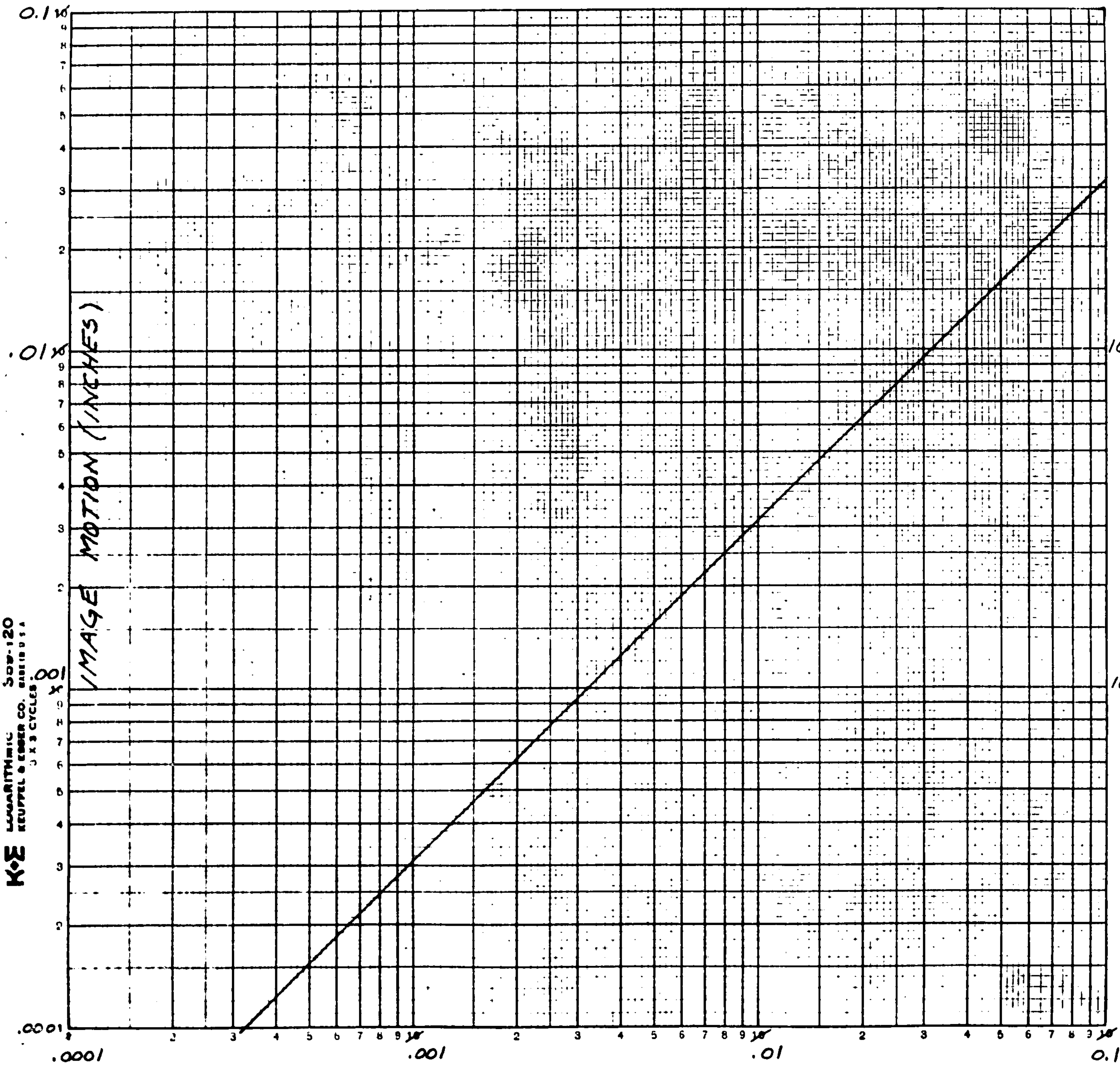

FIGURE 7

 51 L 53

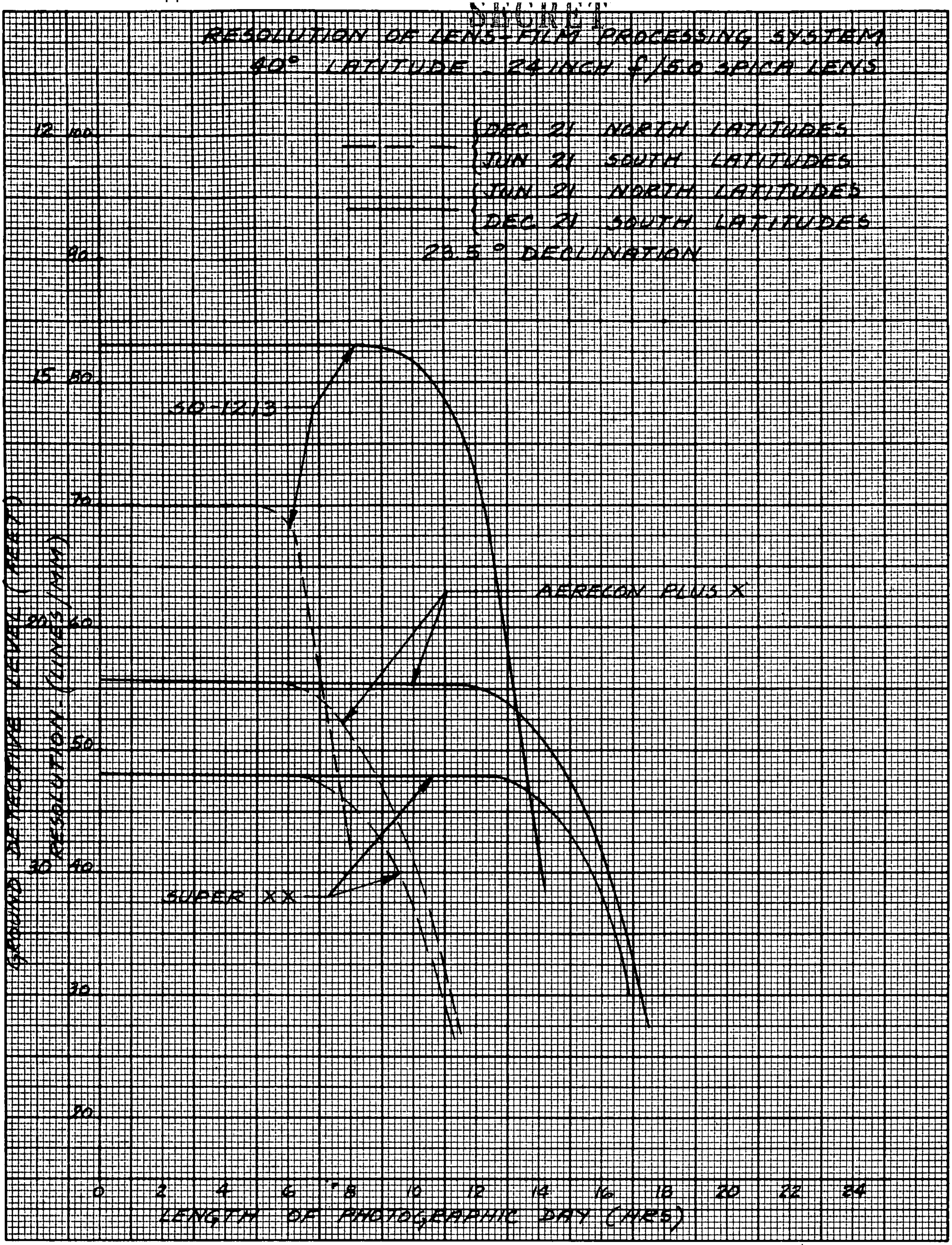

FIGURE 8.

951L54

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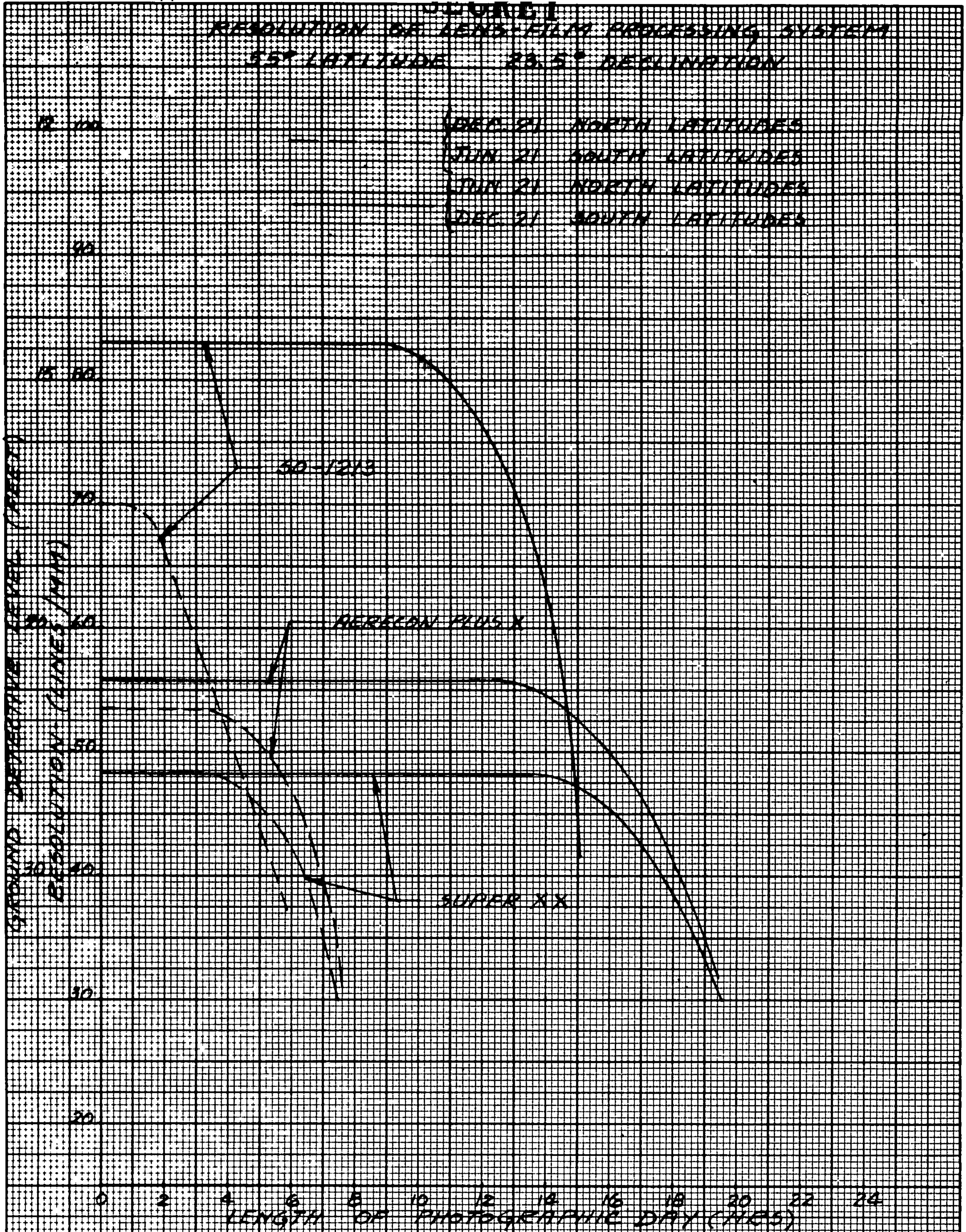

FIGURE 9

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951L55

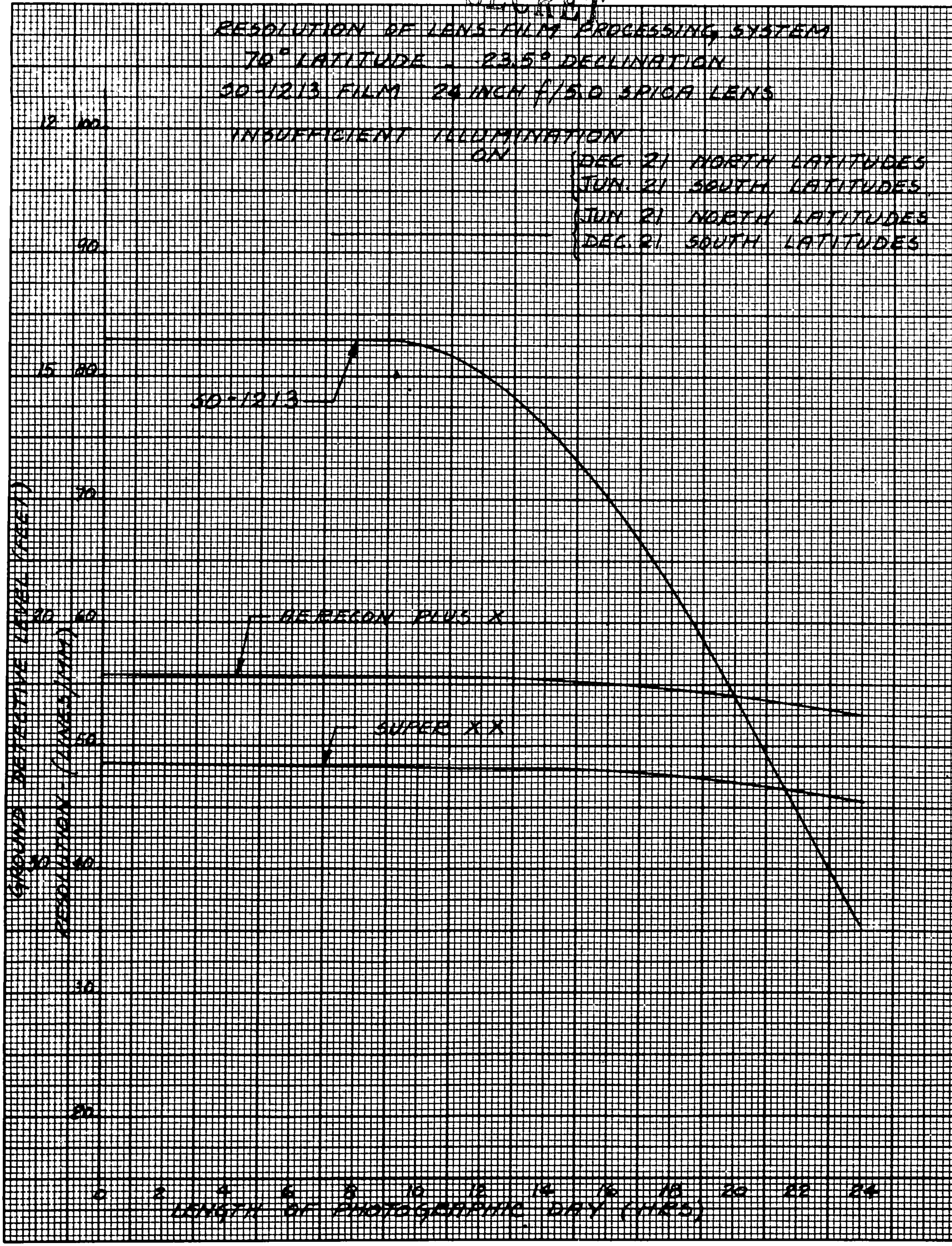

FIGURE 10

 251 L 56

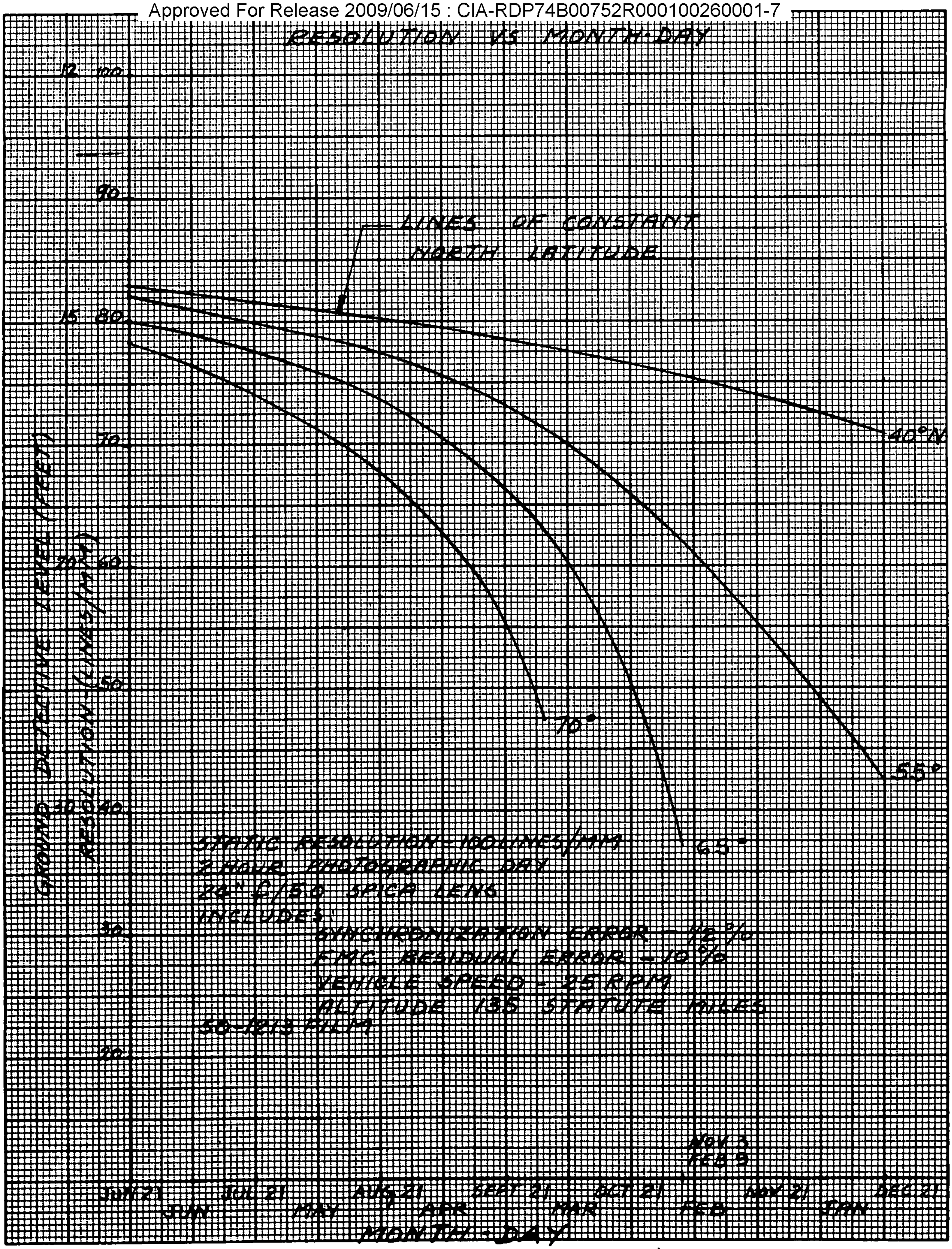

FIGURE 11

951L57

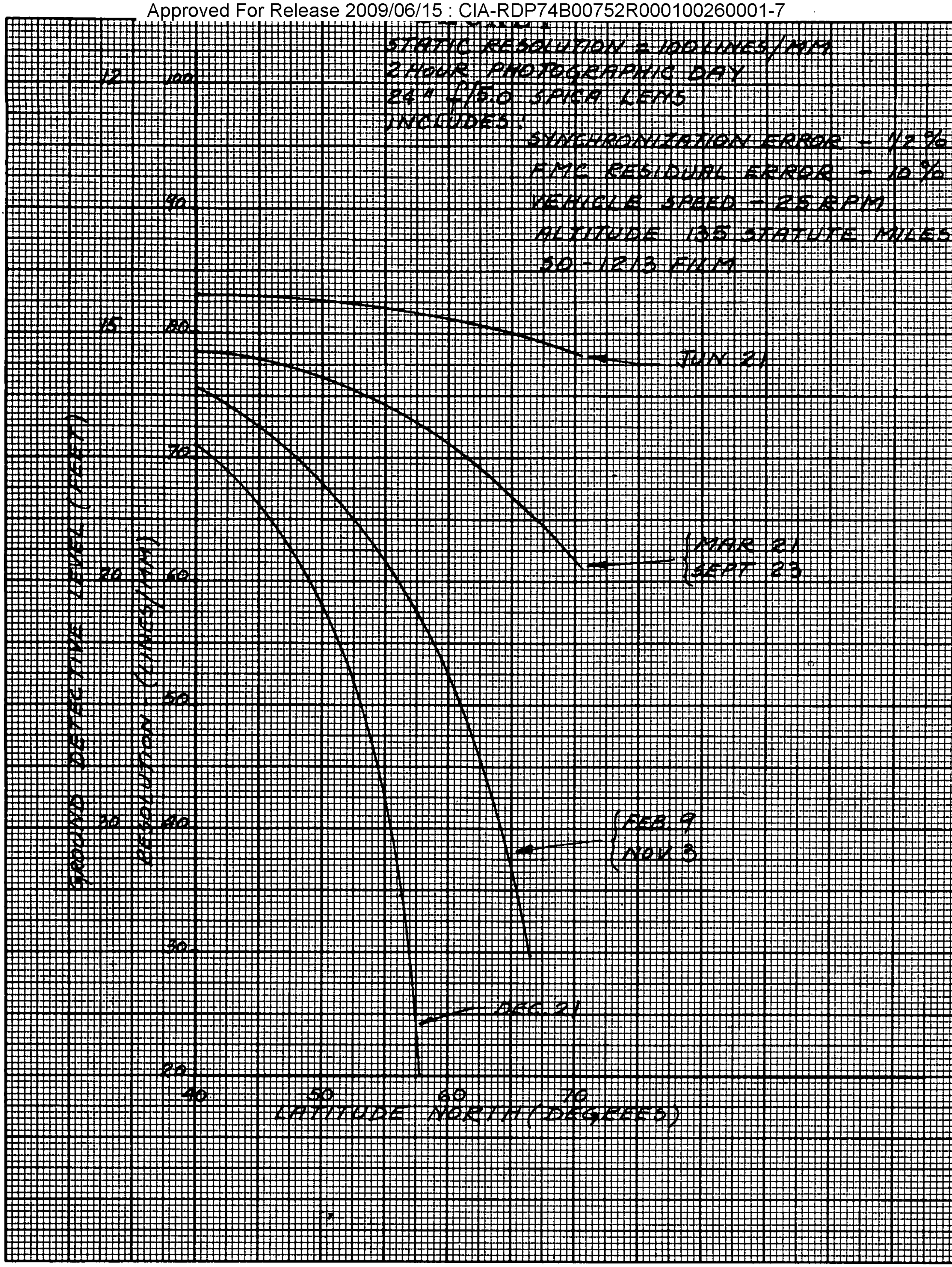

FIGURE 12

951L58

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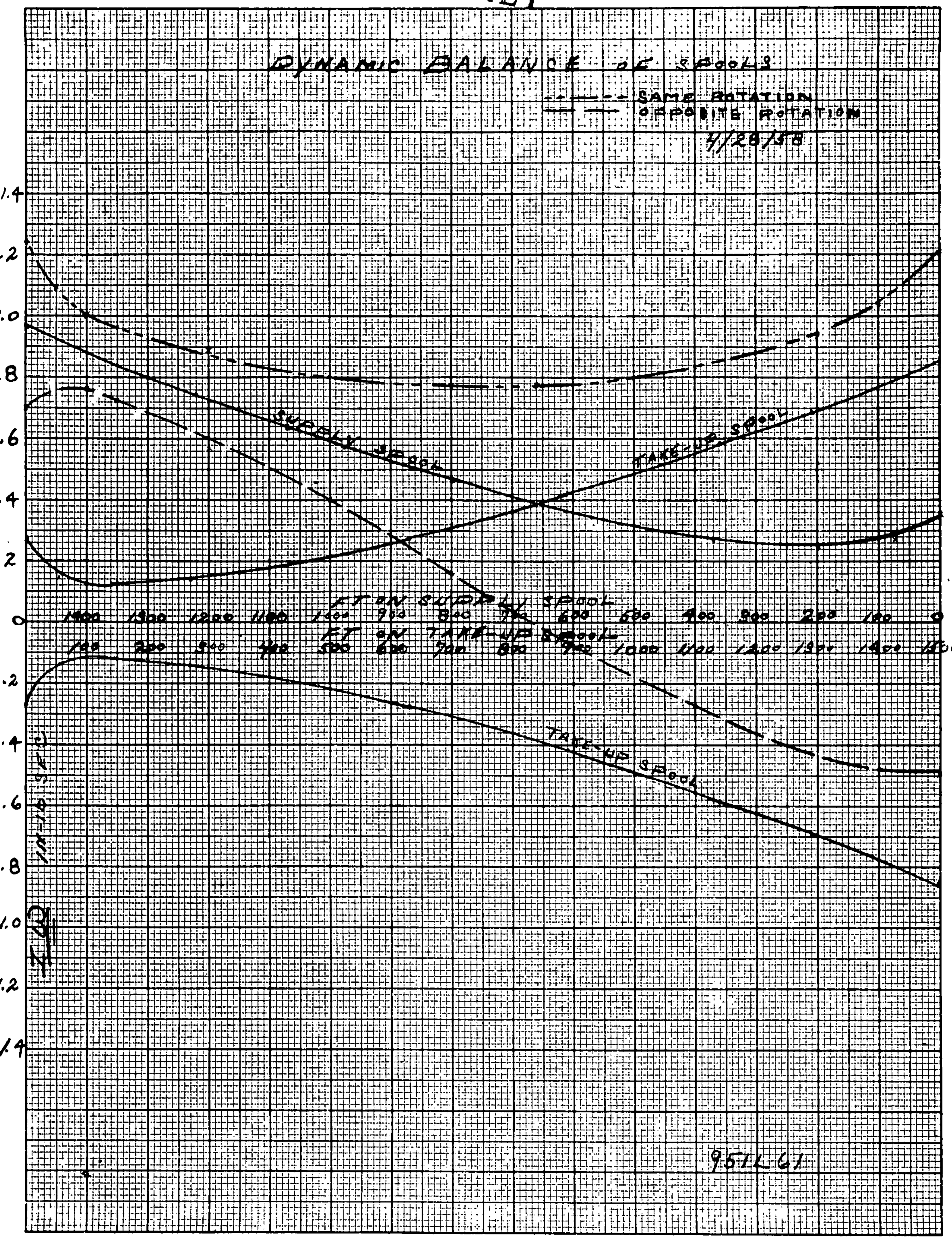
DYNAMIC BALANCE OF SPOOLS
SAME ROTATION
OPPOSITE ROTATION
4/28/58
1.4
1.2
1.0
.8
.6
.4
.2
0
.2
.4
.6
.8
1.0
1.2
1.4
SUPPLY SPOOL
TAKE-UP SPOOL
FT ON SUPPLY SPOOL
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
FT ON TAKE-UP SPOOL
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
TAKE-UP SPOOL
IN-16 SEC
951L61

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

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APPENDIX I

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

Report No. SME-AW-1
25 July 1958

EFFECT OF NON-COINCIDENCE OF THE SPIN AXIS AND THE (MINIMUM) PRINCIPAL AXIS OF INERTIA ON BLUR AND PHOTOGRAMMETRY

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

Report No. SME-AW-1
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SYSTEMS MANAGEMENT & ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

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EFFECT OF NON-COINCIDENCE OF THE SPIN AXIS AND THE (MINIMUM) PRINCIPAL AXIS OF INERTIA ON BLUR AND PHOTOGRAMMETRY

I. INTRODUCTION

In order that the relative image-film motion may be determined, it is desirable to establish a coordinate system which is fixed in the rotating vehicle. Thus, in Drawing 951L30, the symmetry axis (z) is the desired spin axis. The optical axis is perpendicular to this and will be considered either the x or the y axis (both fixed in the vehicle). It is expected that the film motion during exposure will be such as to only compensate for a uniform spin "r_o" about the z axis. Thus the film speed will be "$r_o f$" relative to the camera, "f" being the lens focal length.

The spin axis, upon release, may not coincide with the axis of least moment of inertia "z" and a precessional motion will take place with the result that variable angular velocity components exist about the x, y, z axes. These will cause relative motion of the image with respect to the film. If the velocity has a magnitude (s) and the exposure time is τ the blur is given by equation (1)

$$s = \mathring{s}\tau \qquad (1)$$

II. COMPONENTS OF THE IMAGE MOTION

To describe the image motion in the plane of the film, a plane system of coordinates (u, v) will be utilized (Drawing 951L31). In terms of this system the linear velocity of the image motion can be written as follows:

$$\mathring{s} = \sqrt{\mathring{u}^2 + \mathring{v}^2} \qquad (2)$$

Denoting the angular velocities around x, y and z axes by p, q, and r correspondingly, the relative linear velocities of the image with respect to the film can be written as follows (denoting the focal distance by f):

a) For rotation about x axis

$$\dot{v} = fp \tag{3}$$

b) For rotation about z axis

$$\dot{u}_1 = f\,(r - r_o) = fr_1 \tag{4}$$

c) For rotation about y axis

$$\dot{u}_2 = vq \tag{5}$$

Since the slit is oriented along v-axis and is sufficiently narrow the component u_2 can be considered as parallel to the u axis and its direction depends on the sign of the v coordinate. Adding equations (4) and (5) we obtain for $\dot{u}$

$$\dot{u} = \dot{u}_1 + \dot{u}_2 = vq_1 + fr_1 \tag{6}$$

and equation (2) can be written as

$$s = \sqrt{f^2\,p^2 + (vq + fr_1)^2} \tag{7}$$

III. DETERMINATION OF ANGULAR VELOCITIES

Ascribing the moments of inertia around x, y and z axes as A, B and C correspondingly and using the condition $A > B > C$ Eulers equations of motion for a body subject to no external torque can be written in the form

$$\begin{aligned} \dot{p} &= \frac{B-C}{A}\,qr \\ \dot{q} &= \frac{C-A}{B}\,rp \\ \dot{r} &= \frac{A-B}{C}\,pq \end{aligned} \tag{8}$$

The solutions of these equations can be written in the elliptic functions as follows:

$$p = p_o \operatorname{cn} \lambda t$$
$$q = h \operatorname{sn} \lambda t \qquad (9)$$
$$r = r_o \operatorname{dn} t = r_o \sqrt{1-k^2 \operatorname{sn}^2 \lambda t}$$

The equations (8) solved in terms of (9) give

$$h^2 = \frac{A(A-C)}{B(B-C)} \left(p_o^2 \right) \qquad (10)$$

$$\lambda^2 = \frac{(A-C)(B-C)}{AB} \left(r_o^2 \right) \qquad (11)$$

$$k^2 = \frac{A}{C} \frac{(A-B)}{(B-C)} \left(\frac{p_o^2}{r_o^2} \right) \qquad (12)$$

Initial values p_o and r_o can be determined from consideration of the motion at the instant when $t = 0$ (Drawing 951L32), as

$$p_o = w \sin\beta \ , \ r_o = w \cos\beta$$

where β is the angle between z-axis and the direction of the resultant angular velocity (direction of the spin-axis) at time $t = 0$. The computations for the range of β from 0° to 5°, using the values $A = 3.3C$, $B = 3.0C$ and $w = 18.2$ rpm $- \frac{2\pi}{60} \times 18.2$ rad/sec $= 1.905$ rad/sec. are presented in the Table below:

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TABLE 1

β	p_o	p_o^2	r_o	r_o^2	h	h^2	k^2	λ
0°	0	0	1.905	3.64	0	0		
1°	.0333	.0011	1.905	3.64	.0374	.00140	.00015	1.301
2°	.0663	.0044	1.904	3.63	.0748	.00559	.0006	1.299
3°	.0994	.0099	1.902	3.62	.112	.0126	.0013	1.297
4°	.133	.0177	1.900	3.61	.150	.0225	.0025	1.295
5°	.166	.0276	1.898	3.60	.187	.0351	.0038	1.293

The properties of the elliptic functions are such that for $k^2 \ll 1$, which is the case, they can be approximated by trigonometric functions, and the equations (9) can be rewritten as follows:

$$p = p_o \cos \lambda t \qquad (13)$$

$$q = h \sin \lambda t \qquad (14)$$

$$r = r_o \sqrt{1 - k^2 \sin^2 \lambda t} \qquad (15)$$

Evaluation of $k^2 \sin^2 \lambda_2 t$ shows that in the considered range of β it never exceeds .002 or $k^2 \sin^2 \lambda t < .002$ which justifies the approximation of (15) by

$$r = r_o \left[1 - (1/2)\, k^2 \sin^2 \lambda t\right] \qquad (16)$$

the variable component of (16), which will contribute to the blur (Drawing 951L33) may be written from (16), as follows:

$$r_1 = r - r_o = -\frac{1}{2} r_o k^2 \sin^2 \lambda t$$

and finally all angular velocities will be expressed by:

$$\begin{aligned} p &= p_o \cos \lambda t \\ q &= h \sin \lambda t \\ r_1 &= -\frac{1}{2} r_o k^2 \sin^2 \lambda t \end{aligned} \qquad (17)$$

IV. BLUR DETERMINATION

Combining (1), (7), and (17) the general equation for the blur can be written, as follows:

$$s = \tau \sqrt{f^2 p_o^2 \cos^2 \lambda t + v^2 h^2 \sin^2 \lambda t - 1/2\, vfhr_o k^2 \sin^3 \lambda t + 1/4\, f^2 r_o^2 k^4 \sin^4 \lambda t}$$

The last term under the radical can be neglected giving equation (18)

$$s = \tau \sqrt{f^2 p_o^2 \cos^2 \lambda t + v^2 h^2 \sin^2 \lambda t - \frac{1}{2} vfhr_o k^2 \sin^3 \lambda t}$$

For the case $\beta = 5°$ (f = 12 inches, v = 2.25 inches) the values of the coefficients are:

$$f^2 p_o^2 = 4.03$$

$$v^2 h^2 = .18 \qquad (4.5\%)$$

$$1/2\, vfhr_o k^2 = 0.18 \qquad (.5\%)$$

From these values we conclude that the extreme blur is determined essentially by the first term under the radical of eq. (18), so that we have as an excellent approximation the equation:

$$s\ max = \tau f p_o \qquad (19)$$

The values of s max are computed and presented in the Table below for values of β from 1 to 5 degrees.

β degrees	1	2	3	4	5
Blur $S_{max.}$ (inches)	1×10^{-4}	2×10^{-4}	3×10^{-4}	4×10^{-4}	5×10^{-4}

V. THE CASE B>A>C

The moments of inertia were specified as $A = B° \pm 10\%$, B and $C = \frac{A}{3}$. For the case considered above it has been assumed $A = B + 10\%$. The case of $A = B - 10\%$, B is essentially equivalent to the optical axis being directed along the x axis. The components of the image motion (Drawing 951L34) will be

$$\dot{u} = u_1 + vp + r_1 f$$

$$\dot{v} = qf$$

and the formula for blur will be

$$S = \tau \sqrt{v^2 p_o^2 \cos^2 \lambda t + f^2 h^2 \sin^2 \lambda t - vfp_o r_o k^2 \cos \lambda t + + 1/4\, f^2 v_o^2 k^4 \sin^4 \lambda t}$$

The values of each term are (for $\beta = 5°$, $f = 12$ inches, $v = \pm 2.25$ inches)

$$v^2 p_o^2 = .142$$

$$f^2 h^2 = 5.04$$

$$vfp_o r_o k^2 = .323$$

$$1/4\, f^2 r_o^2 k^4 = .0002$$

and the extreme value of the blur will be given very closely by $S_{\dot{max}} = \tau fh$

β degrees	1	2	3	4	5
$S_{\dot{max}}$ (inches)	1.1×10^{-4}	2.2×10^{-4}	3.3×10^{-4}	4.4×10^{-4}	5.5×10^{-4}

so that the blur is larger by 10% than for the case where the lens axis coincides with the major principal axis.

VI. THE ANGLE BETWEEN THE SPIN AXIS AND THE MOMENTUM VECTOR

The angle between the spin axis and the momentum vector at time $t = 0$ is denoted by α in Drawing 951L32. Then the relationship between α and β may be established as follows:

$$\tan\beta = \frac{p}{r}; \quad \tan(\alpha + \beta) = \frac{Ap}{Cr} = \frac{A}{C} \tan\beta$$

$$\text{or} \quad \frac{\tan\alpha + \tan\beta}{1 - \tan\alpha \tan\beta} = \frac{A}{C} \tan\beta$$

$$\text{and} \quad \tan\alpha = \frac{\frac{A-C}{C} \tan\beta}{1 + \frac{A}{C} \tan^2\beta}$$

but $\frac{A}{C} \tan^2\beta \ll 1$, so that $\tan\alpha = \frac{A-C}{C} \tan\beta$ and for $A = 3.3C$, $\frac{A-C}{C} = 2.3$ and $\tan\beta = \frac{\tan\alpha}{2.3}$. Drawing 951L35 presents "β" as a function of "α".

VII. PHOTOGRAMMETRIC CONSIDERATIONS

The transformation equations relating the coordinates (u, v) of the negative to their projection on the horizontal ground plane (assuming the spin axis to be horizontal) are (Drawing 951L36)

$$U = h \tan\gamma \qquad (21)$$

$$V = \frac{h}{f} \times \frac{v}{\cos\gamma} \qquad (20)$$

where $\gamma = \frac{u}{f}$ in radians.

Ten degree increments of γ with $f = 1$ foot, $h = 713 \times 10^3$ feet and $v = 2.25$ inches gives the following dimensions for the outline of this projection.

γ	U	V
	in thousand feet	
0°	0	135
10°	126	137
20°	260	144
30°	412	156
40°	598	176
46-1/2°	752	185

which is shown on Drawing 951L37,

where L - overall length = 2 U max = 1500×10^3 feet

W - maximum width = 2 V max - 370×10^3 feet

The overall exposure time for a single picture is $T = \frac{93°}{360°}$ Tc, where TC - period of the camera rotation

$$Tc = \frac{2\pi}{r_o} = \frac{6.28}{1.9} = 3.3 \text{ sec.}$$

so that T = .26 Tc = .26 x 3.3 sec. During this time, displacement of the optical axis will occur with respect to the ground surface because of the vehicular ground speed v_g and because of the precessional motion of the vehicle. Displacement due to the ground speed v_g during exposure will be along the V axis and can be computed as follows:

$$\Delta V = v_g \quad T = 25 \times 10^3 \times .85 = 21 \times 10^3 \text{ feet}$$

and can be accounted for.

Evaluation of the displacement due to the precessional motion is equivalent to the problem of blur determination and the formula (19), with modifications, can be utilized.

An upper limit to the displacement can be determined from

$$S_{max} = p_o \; TD \tag{23}$$

where **D** - distance from the nodal point of the lens to the point on the ground.

Measured along the optical axis it is given by:

$$D = \frac{H}{\cos \gamma} \tag{24}$$

and for $\gamma = 46\text{-}1/2°$. $D = 713 \times 10^3 \times 1.379 = 983 \times 10^3$ feet.

T = overall exposure time,

p_o = amplitude of angular velocity around x axis of the vehicle (See Table 1).

The period of the precession is very nearly

$$T_p = \frac{2\pi}{\lambda} \tag{25}$$

From (11) $\lambda^2 = .465\, r_o^2$ or $\lambda = 1.3$ and $T_p = 4.83$ sec. During one quarter of this period p may change from 0 to its maximum value; but the exposure time is shorter than $1/4\ T_p$. Thus equation (23) is pessimistic. Assuming that the angle between the momentum vector and the spin axis (α) does not exceed 3°, the angle between spin axis and Z-axis of the vehicle (β) will not exceed 1°20' and from the Table 1, p_o will not exceed .045.

$$S_{max} = .045 \times .85 \times 983 \times 10^3 = 37 \times 10^3 \text{ feet.}$$

Relative to the origin of coordinates, the error is half of this value.

$$S_{max} = 18 \times 10^3 \text{ feet.}$$

This is the displacement at the edge of the negative ($\gamma = 46\text{-}1/2°$), where the width of the projected negative is $W = 2V\ max = 370 \times 10^3$ feet so that S_{max} is about 5% of W. For the case where the spin axis is not parallel to the horizontal plane, which is equivalent to the case of the optical axis deviating from the vertical by the angle "t" (tilt angle) this displacement in the plane of the scanning optical axis will be larger by a factor of sec (t), which (for $t = 15°$) is sec $15° = 1.035$.

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Defense Products Division
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GENERAL REFERENCES ON RIGID BODY MOTIONS

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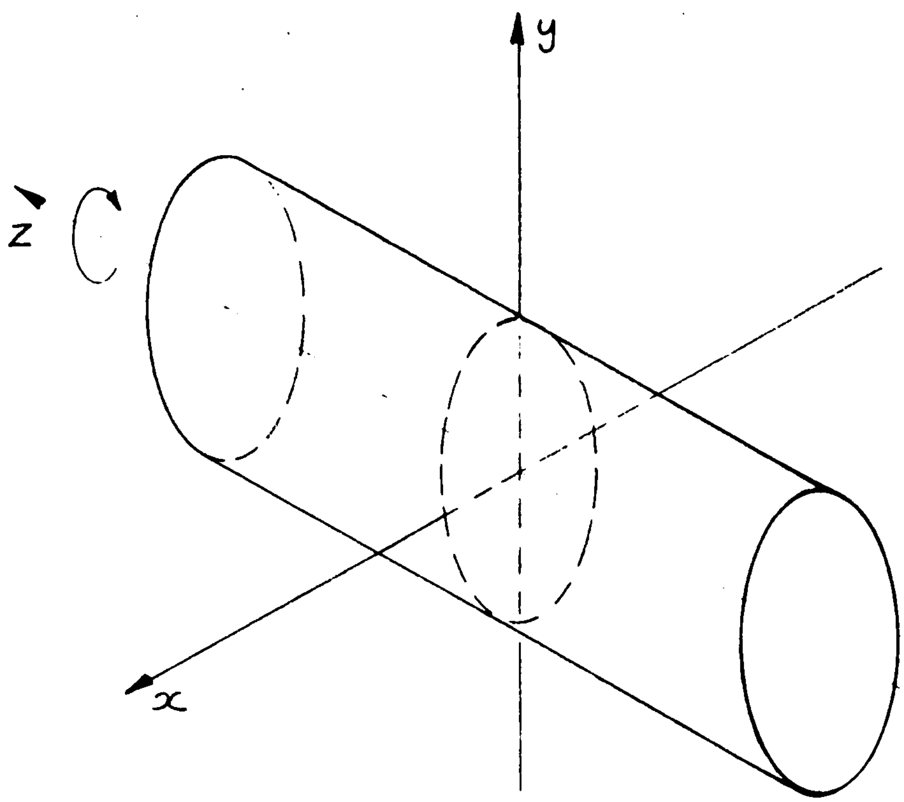

FIG. 1

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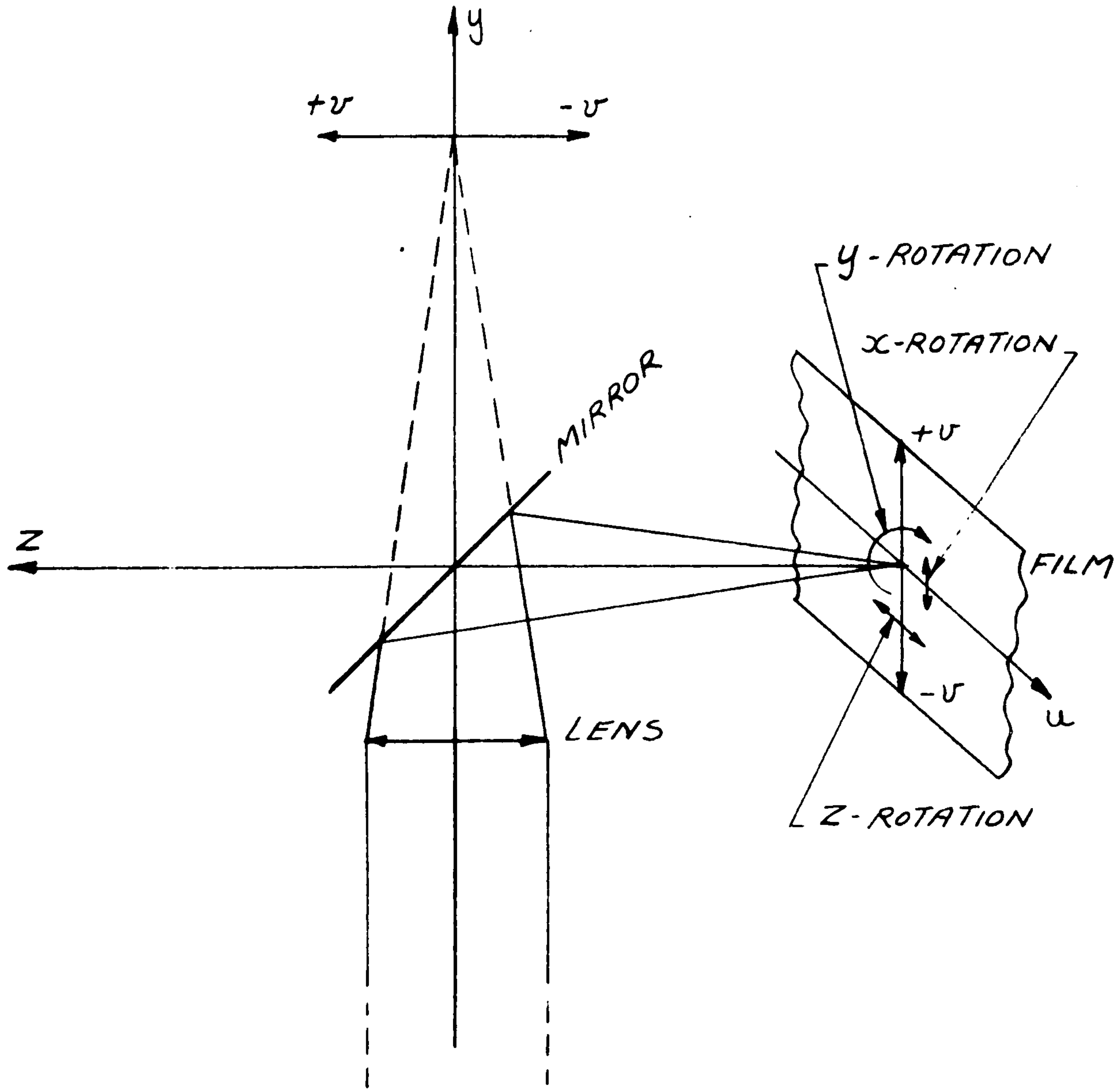

FIG. 2

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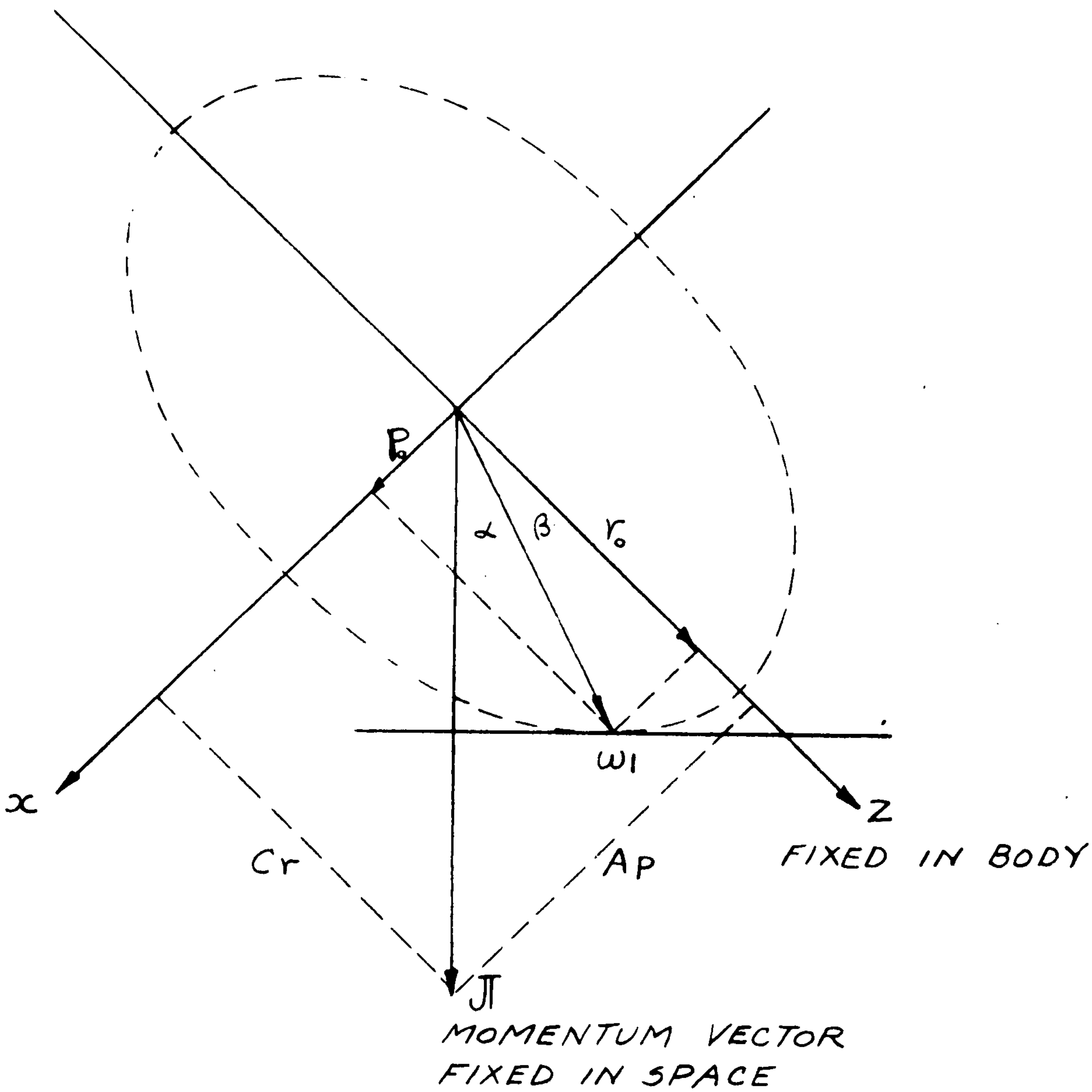

ANGULAR RELATIONSHIPS AT TIME $t=0$

FIG. 3

951L32

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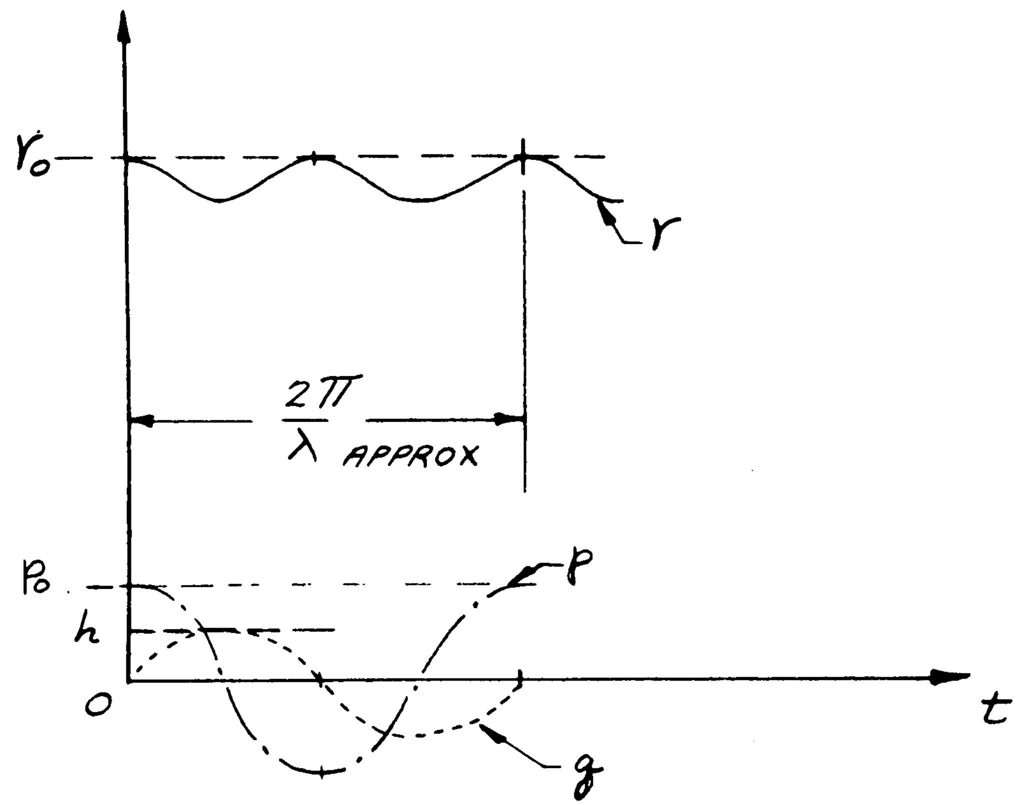

FIG. 4

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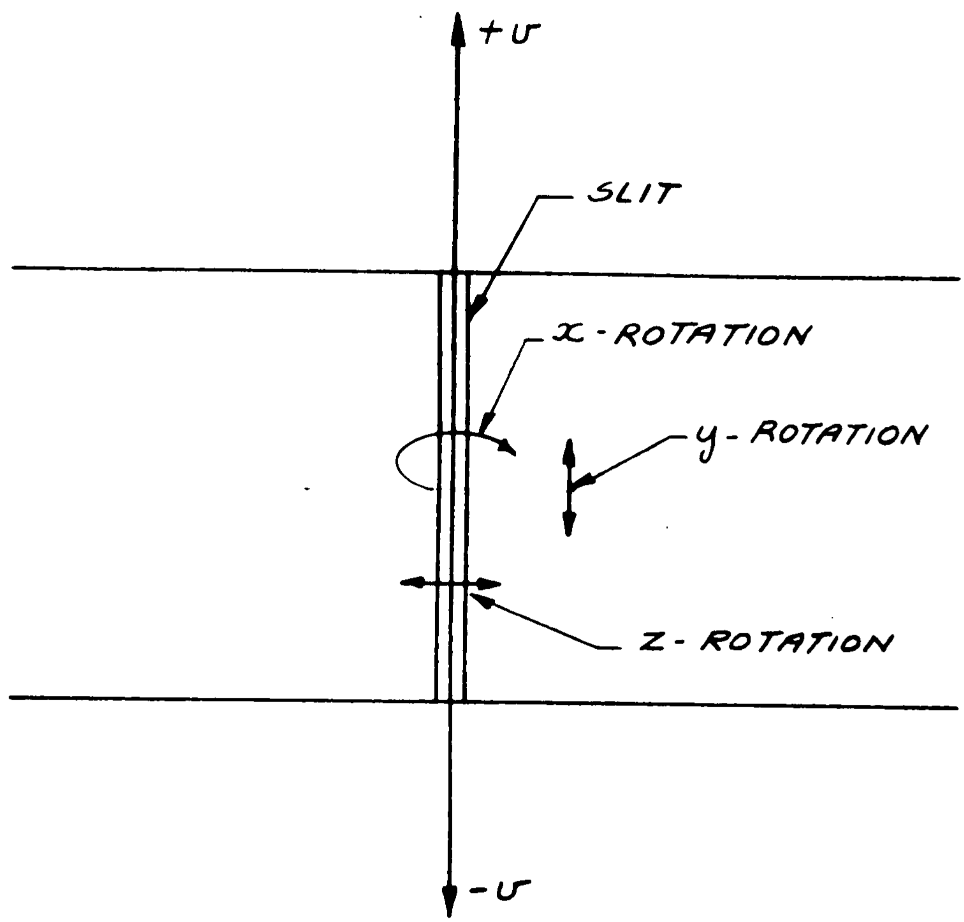

FIG. 5

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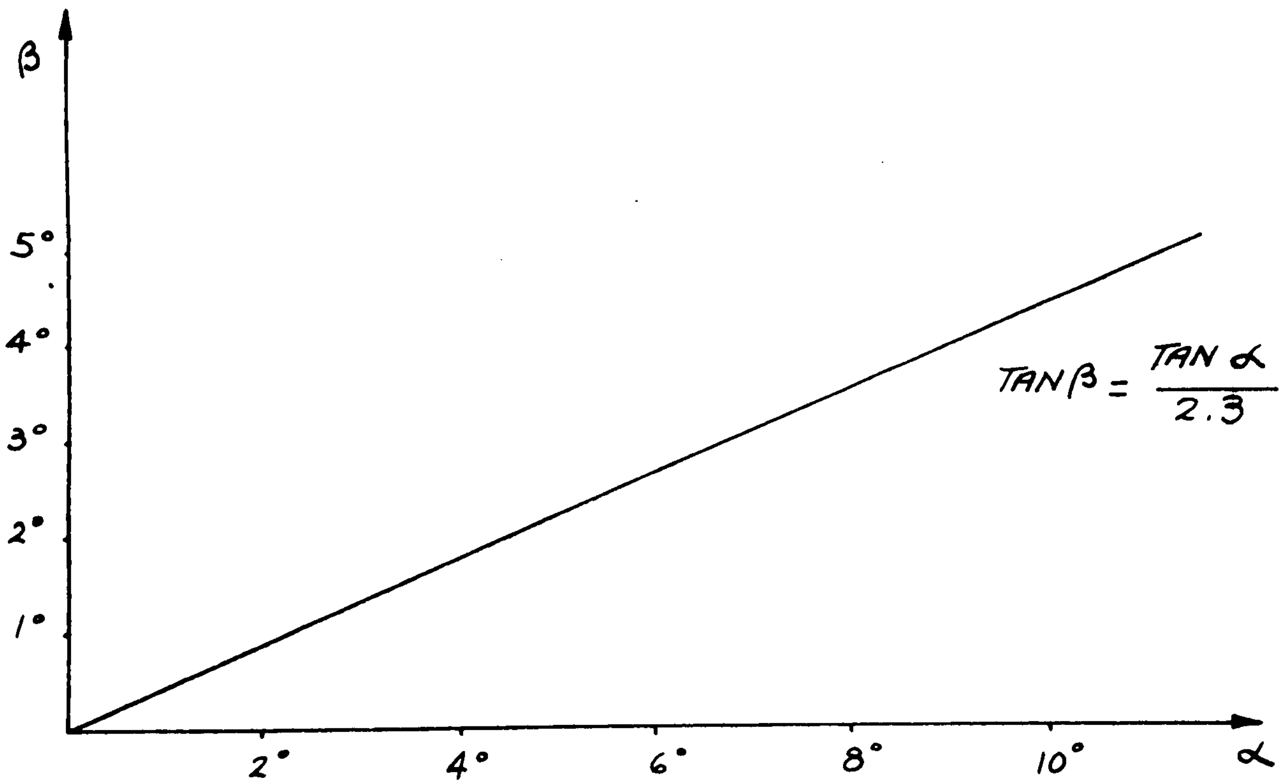

FIG. 6

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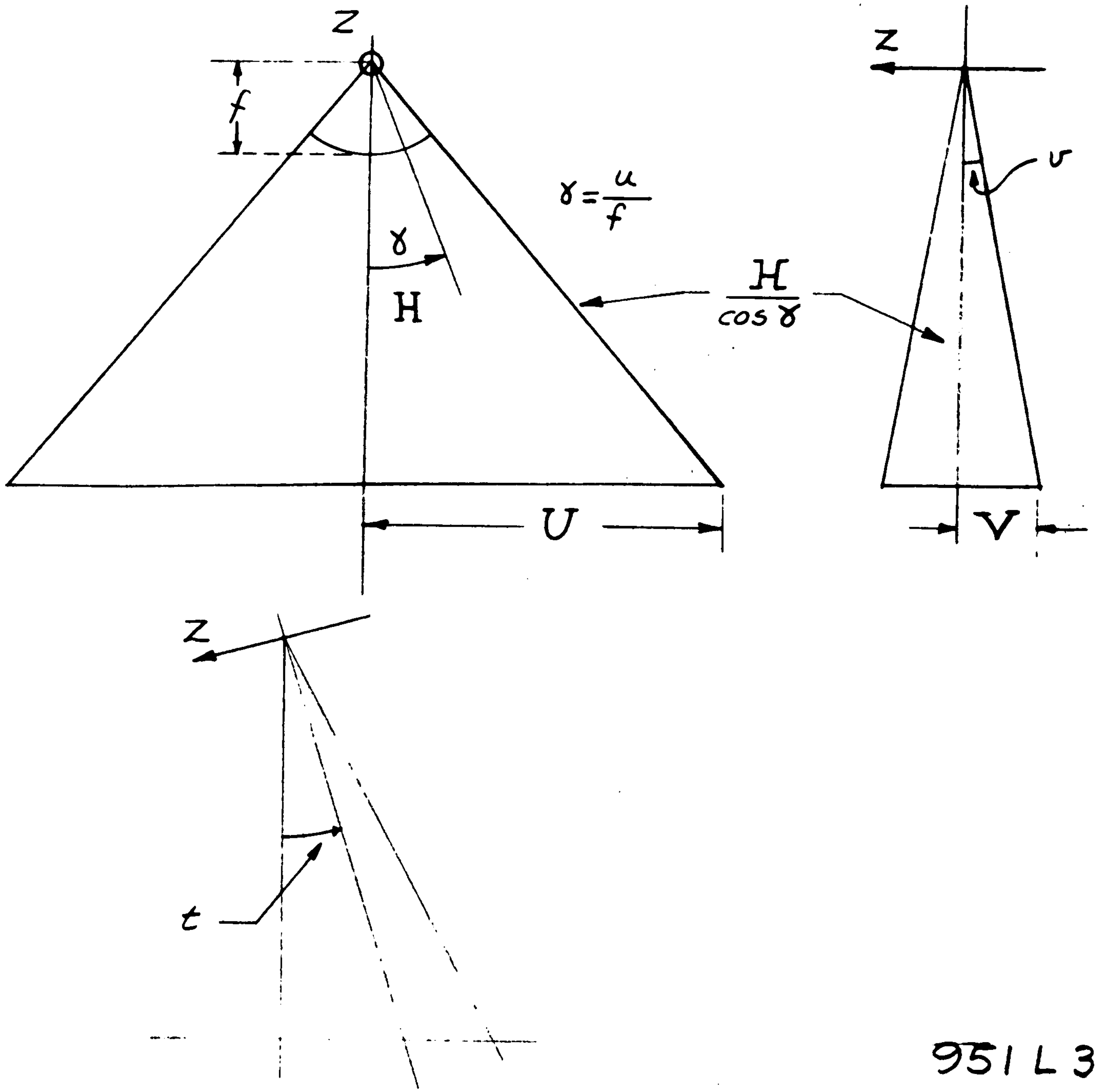

FIG. 7

951 L 36

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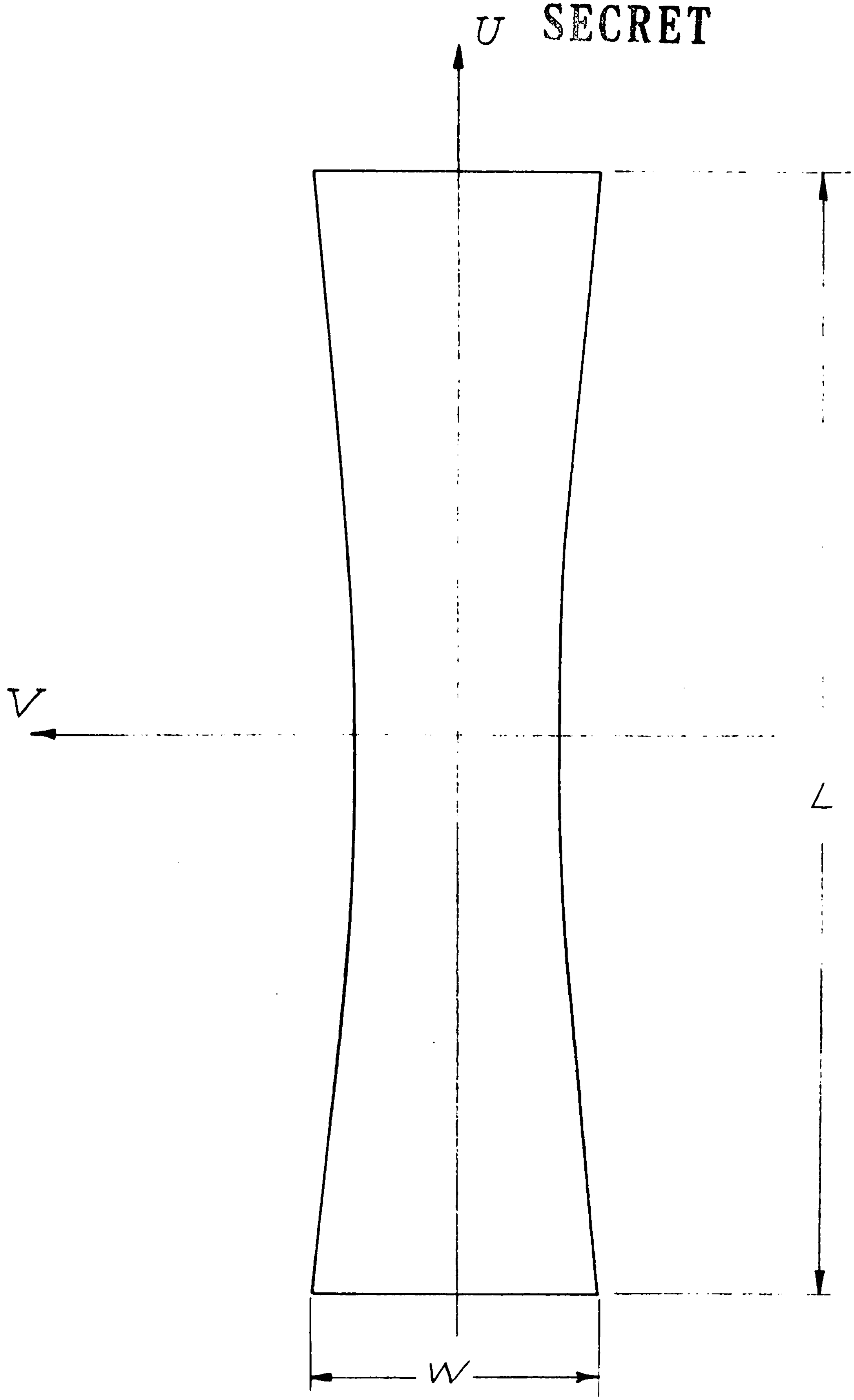

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FIG. 8

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SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

Report No. SME-AF-1
25 July 1958

APPENDIX II

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

Report No. SME-AF-1
27 March 1958

EFFECTS ON PHOTOGRAPHIC FILM RESULTING FROM IMMERSION IN SALT WATER AND SALT WATER PLUS YELLOW DYE MARKER

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

Report No. SME-AF-1
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SECTION I

INTRODUCTION

The purpose of this investigation was to determine the sensitometric and physical effects on Type IB Class L film resulting from immersion in sea water and in sea water plus yellow dye marker for up to 72 hours.

In general, after immersion, film contrast, maximum density, and density scale increased, base plus fog density remained unchanged, and film speed decreased. No physical damage was apparent except when wetted film was allowed to dry or the film was only partially wetted (so as to be tacky). No effect was noted on sensitometric characteristics as a result of an 11,000 g shock.

It was recommended that extreme care be taken to keep the film either completely wet or completely dry. If wetting cannot be avoided, complete data should be obtained on loss of film speed (which from these tests appears to be 1/2 to 1 stop) and on revised processing procedures required to obtain the desired sensitometric characteristics for the particular film chosen. It would be desirable to determine the effects of sea water immersion on resolution, acuity, and granularity.

SECTION II

PROCEDURE

Four solutions were chosen for these tests; sea water and sea water plus 10 ppm, 100 ppm, and 1,000 ppm yellow dye marker. Type IB Class L film (Super XX- RP) was used in all tests.

A total of 24 test conditions as tabulated in Table 1 were investigated. Use of a 700 ft. roll for each condition would be prohibitively expensive. Therefore, initial efforts were directed towards obtaining a correlation between results of immersion of a complete 700 foot roll of 5 inch perforated film and immersion of standard sensitometric film strips (9-3/4 inches x 35 mm).

After each test procedure was completed, the sensitometric strips were developed for 5 minutes in Eastman Kodak D-19 at 70°F, and stopped, fixed, washed, and dried in the conventional manner. Strip densities were then read and H & D curves constructed. A detailed description of the test procedure can be found in the Appendix.

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TABLE I

TEST CONDITION	SEA WATER	SEA WATER PLUS YELLOW DYE MARKER IN CONCENTRATION OF: 10ppm	100ppm	200ppm	1,000ppm
1. Soak for 48 hrs., let dry, set for 48 hrs. and process	Strips*	Strips	Strips	-	Strips
2. Soak for 70 hrs., then rinse in running fresh water for:					
a. 5 minutes	Strip	Strip	Strip	-	Strip
b. 10 minutes	Strip	Strip	Strip	-	Strip
c. 15 minutes	Strip	Strip	Strip	-	Strip
d. 20 minutes	Strip	Strip	Strip	-	Strip
3. Soak for 72 hrs., 24 hrs. fresh water soak while on spool, then process. Film subjected to 11,000 g's shock for about $40\text{-}80.10^6$ sec. prior to immersion.	Strip-700 ft. roll	Strip	Strip	Strip-700 ft. roll	Strip

*"Strip" refers to 9-3/4 inch by 35 mm Sensitometric Strip.

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SECTION III

RESULTS

Sensitometric results are shown in Figures 1,2,3,4,5,6, and 7. Figures 1,2,3, and 4 are H&D curves showing results of film immersion in sea water and sea water plus yellow dye marker followed by a running fresh water wash for several different times. Figures 5,6, and 7 are plots of fog level, eleventh step (on sensitometric step tablet) and maximum density for various dye concentrations versus time of fresh water wash after immersion and before processing.

A. Specific Observations (Refer to Table I)

1. Test Condition 1, Table I

The film samples were dried after sea water-dye marker immersion and before processing.

a. All seven film strips were highly fogged and had highly varigated densities. Only one strip was readable.

2. Test Condition 2, Table I

Results are shown in Figures 1 through 7. The H&D curves show that the strips wound in a tight coil had a lower fog and maximum density than strips completely exposed to the solution. Apparent film speeds of both coiled and uncoiled strips were lower than the control strip, with the coiled strips having higher speeds than the uncoiled strips in all but one test.

The length of rinse time after sea water and sea water plus dye immersion from 5 to 20 minutes had no measurable effect on sensitometric results.

3. Test Condition 3, Table I (strips)

Results are shown in Figure 1. From Figure 1 it can be seen that a strip immersed in sea water gives sensitometric results that are extremely similar to the wedge exposure on the 700 ft. roll. On this basis, it is proposed that the coiled strips be used as a reasonable measure of the effect of sea water on the spooled film.

4. Test Condition 3, Table I, Fresh Sea Water with 700 ft. roll of Film.

a. The sea water was colorless at start of test, after film immersion the water became amber color and had an orange-yellow suspension of small particles. This indicates serious leaching of the emulsion or anti-halation back coating.

b. The inboard wedge (close to spool core) was clean.

c. The wedge in the center of the roll was clean.

d. The outboard wedge (close to outside wrap of spool) was clean. Figure 1 is an H&D plot of the wedges obtained from this test along with a control wedge plot.

5. Test Condition 3, Table I, Sea Water plus 200 ppm Dye Marker

a. The first fifty feet or so of the 700 ft. roll was stained by dye-sea water solution. The remaining film was wetted only at the perforations. The inboard, or core end, was affected in the same manner.

b. The major damage consisted of emulsion sticking to the film base resting against it. Sticking was confined primarily to the perforation area.

c. After film immersion the water became more deeply colored (green-yellow) with a smaller concentration of the orange-yellow particles observed with pure sea water.

d. The outboard wedge (close to the outside wrap on the spool) was badly damaged by pinholes.

e. The inboard wedge (close to the spool core) was damaged by pinholes, but not as severly as the outboard wedge.

f. The wedge in the center of the roll was undamaged.

g. No pressure marks resulting from 11,000 g impact were evident.

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SECTION IV

DISCUSSION OF RESULTS

A. Sensitometric Characteristics

The increase in maximum density, density scale, and contrast and the decrease in apparent film speed shown in Figures 1-4 are not explained. This trend held through all tests where film was immersed in sea water or sea water plus dye marker.

Two important inferences can be drawn from these facts. First, the apparent speed loss of from 1/2 to 1 stop will have to be compensated for during exposure. Higher contrast is normally associated with longer developing times (up to a limit of course). Also, with longer developing times, apparent speed also increases. Since the strips immersed in sea water showed a higher contrast and maximum density and a lower apparent speed, an analogy between sea water immersion and enhancement of developer action, or pre-developing is highly unlikely. The second important consideration is the slightly higher contrast and much higher maximum density, concomitant with a very small increase in base plus fog density. If highly accurate contrast and density scale control is important during film processing, film developing times must be modified, a shorter time being required to obtain the same density scale and contrast for film immersed in sea water. It should be noted that a decrease in developing time will contribute an additional loss in apparent film speed.

As indicated in Figures 5, 6, and 7 the length of fresh water rinse from 5 to 20 minutes after immersion in sea water and before processing, had no measurable effect on sensitometric characteristics.

B. Physical Characteristics

The only serious damage to test samples resulted when the film, once wetted in sea-water, was allowed to dry. When complete rolls were allowed to partially dry or were not completely wetted, film emulsion adhered very strongly to the film base resting against it. Individual strips allowed to dry before processing were extremely mottled, the resulting sensitometric step densities being completely unreadable. This was possibly due to bacterial action on the emulsion.

SECTION V

RECOMMENDATIONS

A. Obviously the film should be completely protected from contact with sea water.

B. If it is impractical, the film, once wetted, should be maintained completely soaked until processed. After recovery, storage in fresh water is preferred to sea water.

C. Future Work

1. If sea water immersion cannot be avoided, more detailed data will have to be obtained on the exact loss of speed resulting from immersion for the specific film to be used and on the modification to processing times that will be required to obtain the desired sensitometric characteristics.

2. If time and resources are available, it would be desirable to determine effects on image "quality" resulting from sea water immersion. By "quality" it is meant as indicated by measurements of resolution, acuity, granularity, etc.

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SECTION VI

APPENDIX

A. Detailed Procedure

1. Tests With Complete Rolls of Film

Materials and Equipment

a. Argon Contact Printer
Exposure 1/25 sec. (filtered by two sheets vellum)

b. D-19 Developer 68°F, 5 min.

c. Two five gallon buckets.

d. Ten gallon fresh salt water.

e. Conc. Dye Marker.

f. 5-1/2 inch film rewind.

g. Super XX IBL, 5-1/2" x 700 ft. spooled.

Method

The film was supplied immediately after the 11,000 g drop test and was rewound on spools. The salt water was obtained fresh from Long Island Sound. Four gallons were put into each bucket; one bucket contained only salt water and to the other bucket was added 3g of dye marker, 3g/4 gal. Three step wedges printed on the argon contact printer using an uncalibrated Kodak step wedge were printed on each 5-1/2" x 700 ft. spool of Super XX film, extreme ends and middle. On 2-15-58 at 1600 hours one spool of film was placed in one bucket containing fresh salt water. The other spool was placed in another bucket containing fresh salt water plus 3g/4 gal. dye marker. The buckets were sealed to prevent light fogging the film.

On 2-18-58, three days later, the exposed wedge portions of the film were cut from the spool and marked accordingly. These wedges were processed in EK D-19 developer for five minutes at 68°F, read on the Eastman Kodak densitometer and plotted along with a control step wedge.

2. Tests With Sensitometric Strips

Materials and Equipment

a. Herrnfeld 1B Printer 2.5 ND + #5900 (day) filter.

b. Super XX 1BL strips, 9-3/4 x 35 mm

c. E.K. D-19 Developer for 5 minutes at 70°F.

d. Four-one liter beakers.

e. Fresh salt water, from Long Island Sound.

f. Dye Marker.

Method

Four-one liter beakers were filled with fresh salt water. To three of the beakers was added 10ppm, 100ppm, and 1,000 ppm of dye marker respectively. Dye marker was not added to the fourth beaker. These beakers were marked accordingly and placed in a large can with a light tight lid.

Strips of Super XX 1BL film were exposed on the Herrnfeld 1B Sensitometer. Four exposed strips were wound tightly into a coil with an extra strip for the inside core and bound by a rubber band. One set of strips bound thusly was immersed in each one of the four beakers. Four loose single strips were also immersed into each one of the four beakers. The lid was placed on the can and taped to eliminate any stray light and set aside gently for 72 hours. At the end of the prescribed time the strips were rinsed for 5, 10, 15, 20 minutes processed and dried. Processing was accomplished by taping exposed film strips to plate glass and placing in a tray of developer. The agitation was provided by constantly rocking each edge of the tray in succession. The densities were then read and curves plotted for the five minute rinse. A graph was plotted showing maximum and minimum density versus time in running water rinse.

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OUTLINE OF PROCEDURE:

1. Soak Strips for 48 hrs. - sea water - let dry and set for 48 hrs. and process.

"	sea water +10ppm dye	"
"	sea water +100ppm dye	"
"	sea water +1000ppm dye	"

Two Conditions (a) wound tight
(b) loose strips

Time Started 1600 2-21-58

Finished 1100 2-24-58

Time 67 hours

2. Soak Strips for 48 hrs. - sea water plus 10ppm dye (0.1g/l)

Finished 1380 2-24-58
Time 69 hours

5 minute running water rinse
10 "
15 "
20 "

3. Soak Strips for 48 hrs. - sea water plus 100 ppm dye (.1g/l)

Finished 1420 2-24-58
Time 70 hours

5 minute running water rinse
10 "
15 "
20 "

4. Soak Strips for 48 hrs. - sea water plus 1000ppm dye (1.0g/l)

Finished 1515 2-24-58
Time 71 hours

5 minute running water rinse
10 "
15 "
20 "

3. Control Strips

Five control strips were exposed and processed in the same manner as the test (no sea water immersion). The density readings of all five strips were found to be identical for all practical purposes.

Test 1 - The two conditions of exposed strips were removed from the solutions of salt water and dye marker and hung up to dry in a light tight container for 48 hours, then processed in D-19 for 5 minutes at 70°F. Seven strips were highly fogged and with varigated densities. Only one strip was readable. It is possible that the first strips taken off each coil was effected by the salt water and dye solutions, and not being processed until after 48 hours in a dry state they were affected by chemical and bacterial action of the salt water and dye solutions.

These strips were not read and plotted.

Test 2 - The two conditions of exposed strips were removed from the solution of salt water and 10 ppm dye marker, placed in a tray of running water for 5, 10, 15 and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The densities of each strip were read.

The strips that were wound tight, emulsion to back, had a lower fog and maximum density than strips that were loose. There was no indicated difference in the 5 minutes rinse through the 20 minute rinse.

Test 3 - The two conditions of exposed strips were removed from the solution of salt water and 100 ppm dye marker, placed in a tray of running water for 5, 10, 15, and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The resulting densities indicate that the strips wound tightly in a coil had a lower fog and maximum density than the strips that were totally exposed to the solution. There is no real difference in the running water rinse, 5 minutes through 20 minutes.

<u>Test 4</u> - The two conditions of exposed strips were removed from the solution of salt water and 1000 ppm dye marker, placed in a tray of running water for 5, 10, 15, and 20 minutes and then processed in D-19 for 5 minutes at 70°F. The resulting densities indicate that the strips wound tightly in a coil had lower fog and maximum densities than the strips that were totally exposed to the solution. The density differences from the running water rinse 5 minutes through 20 minutes is neglegible.

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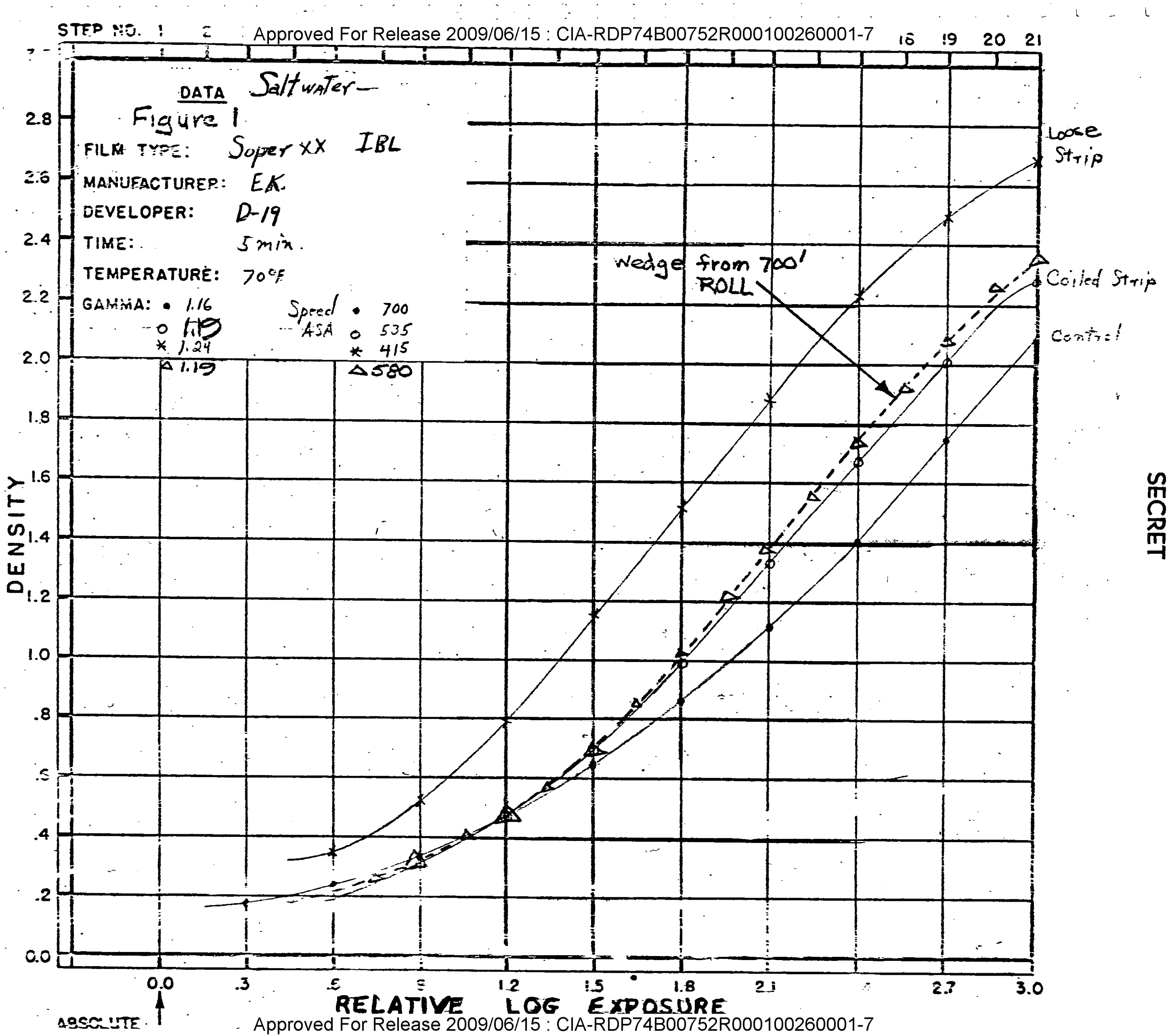

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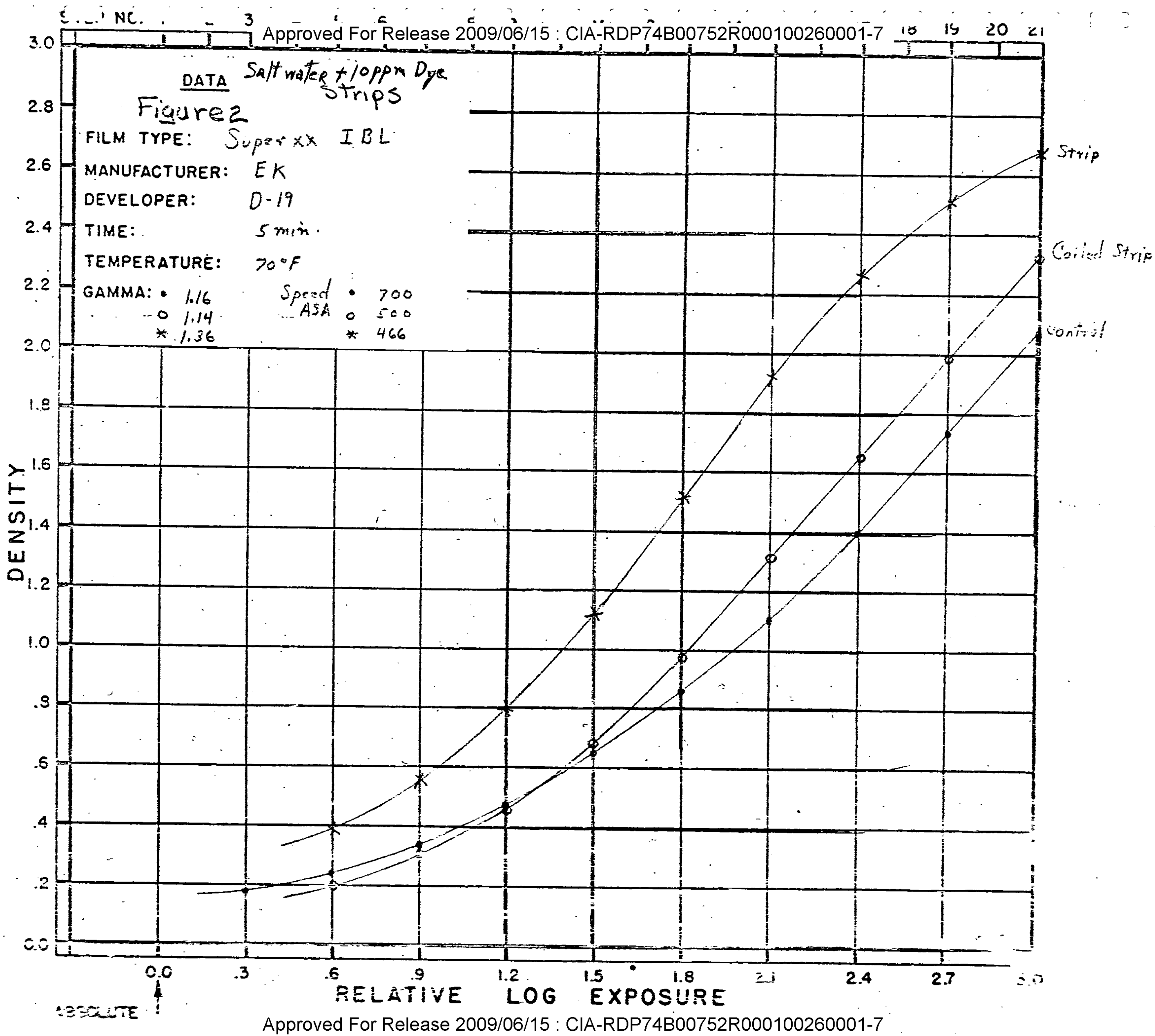

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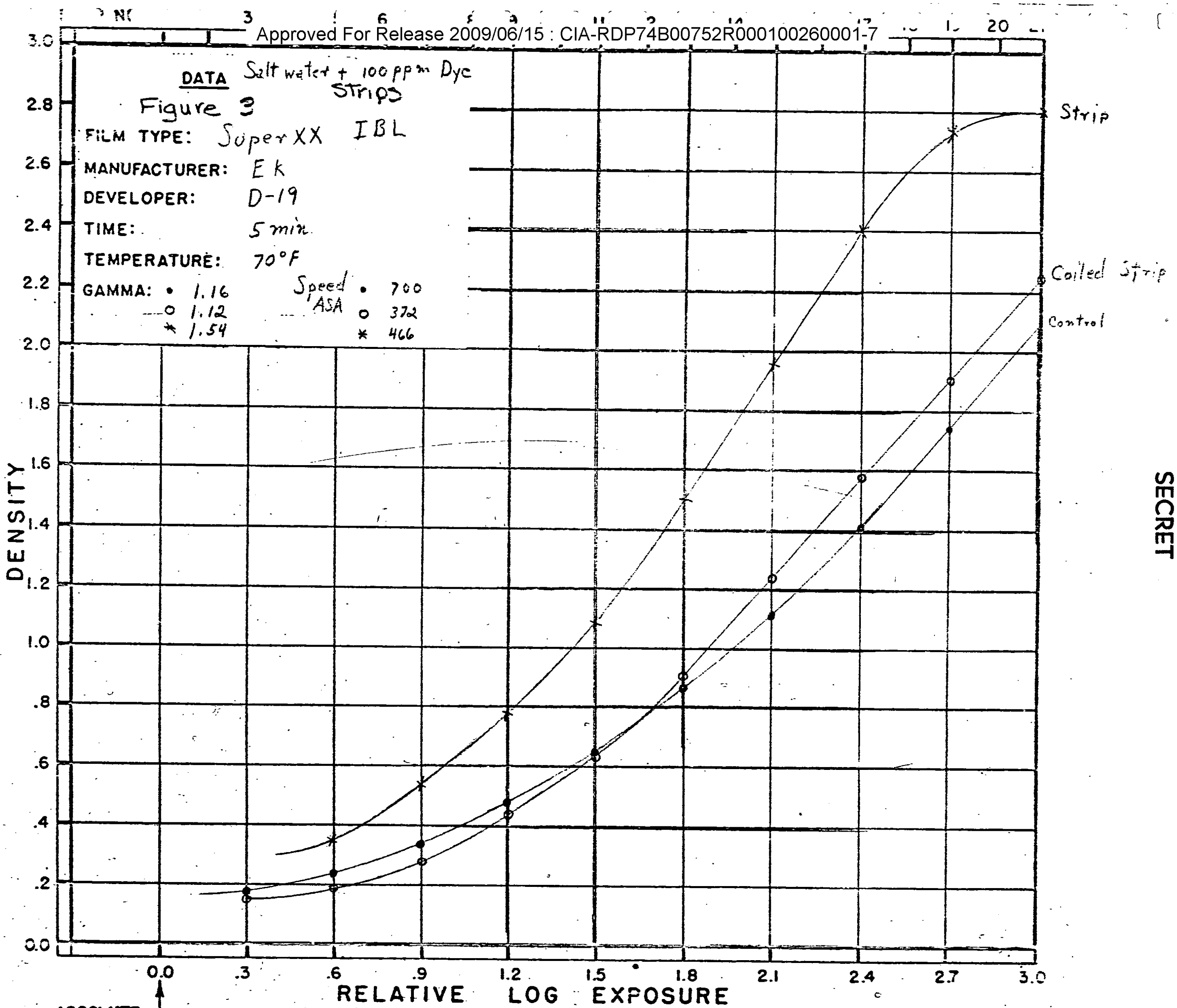

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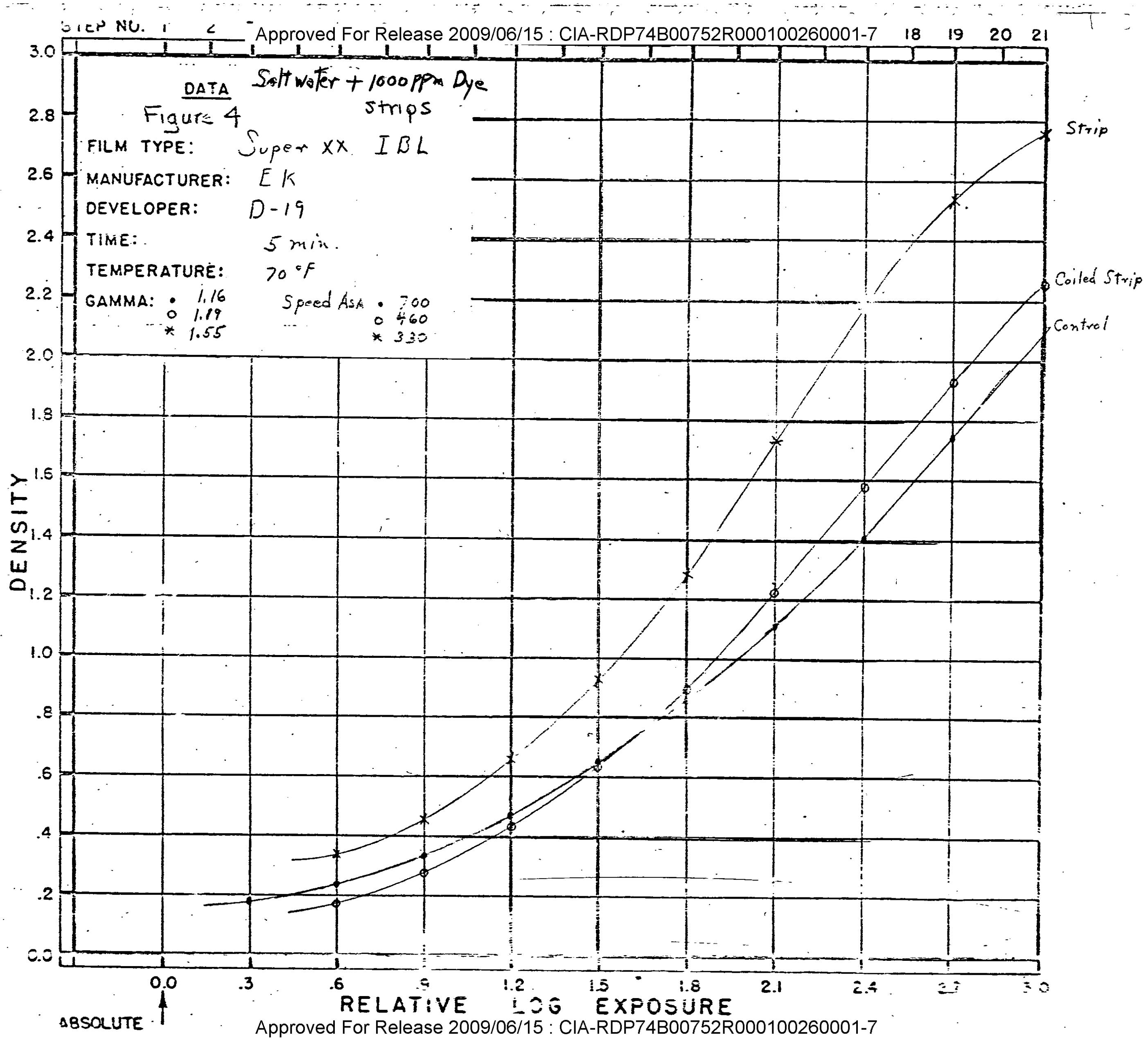

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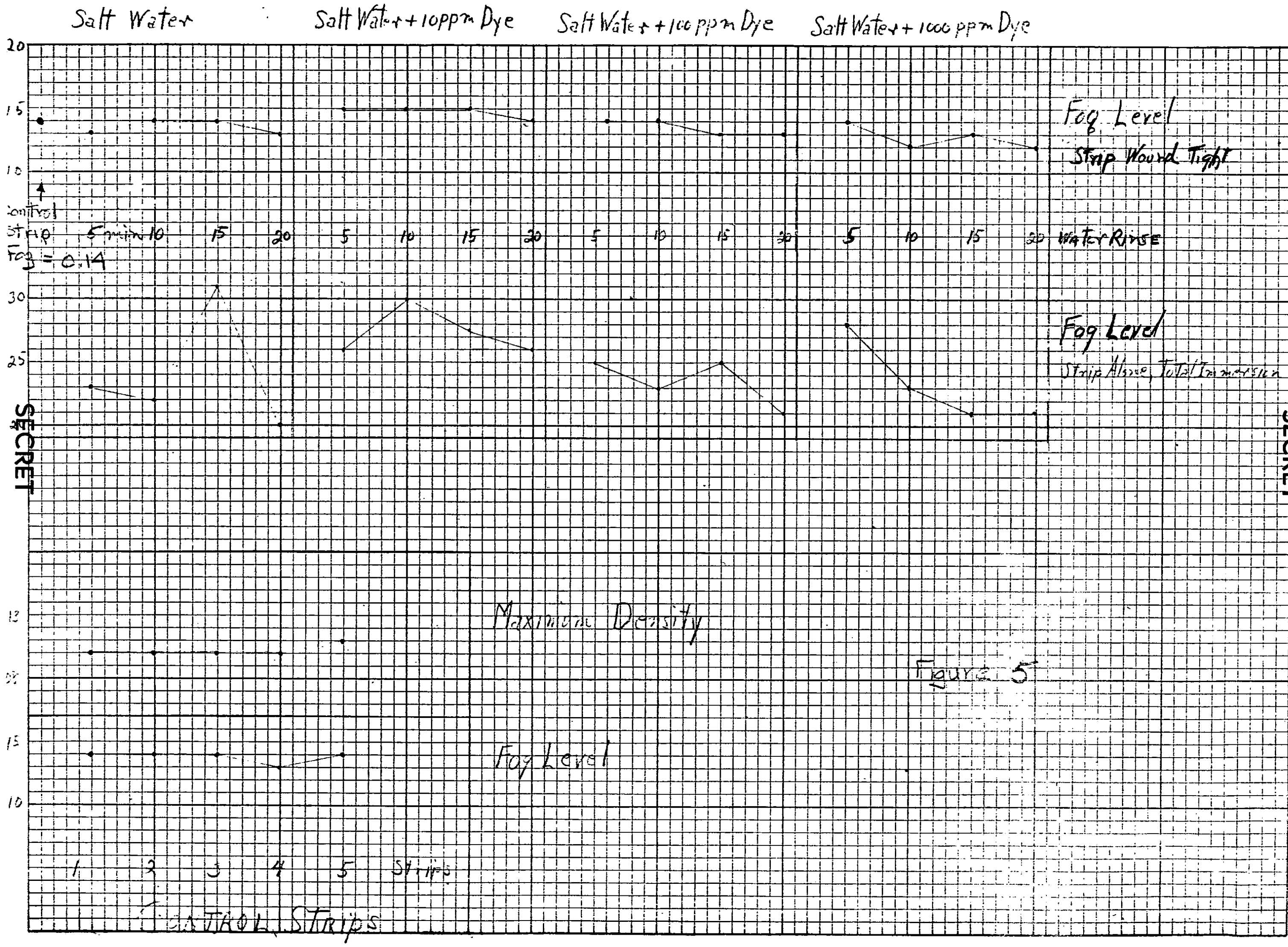

Figure 5

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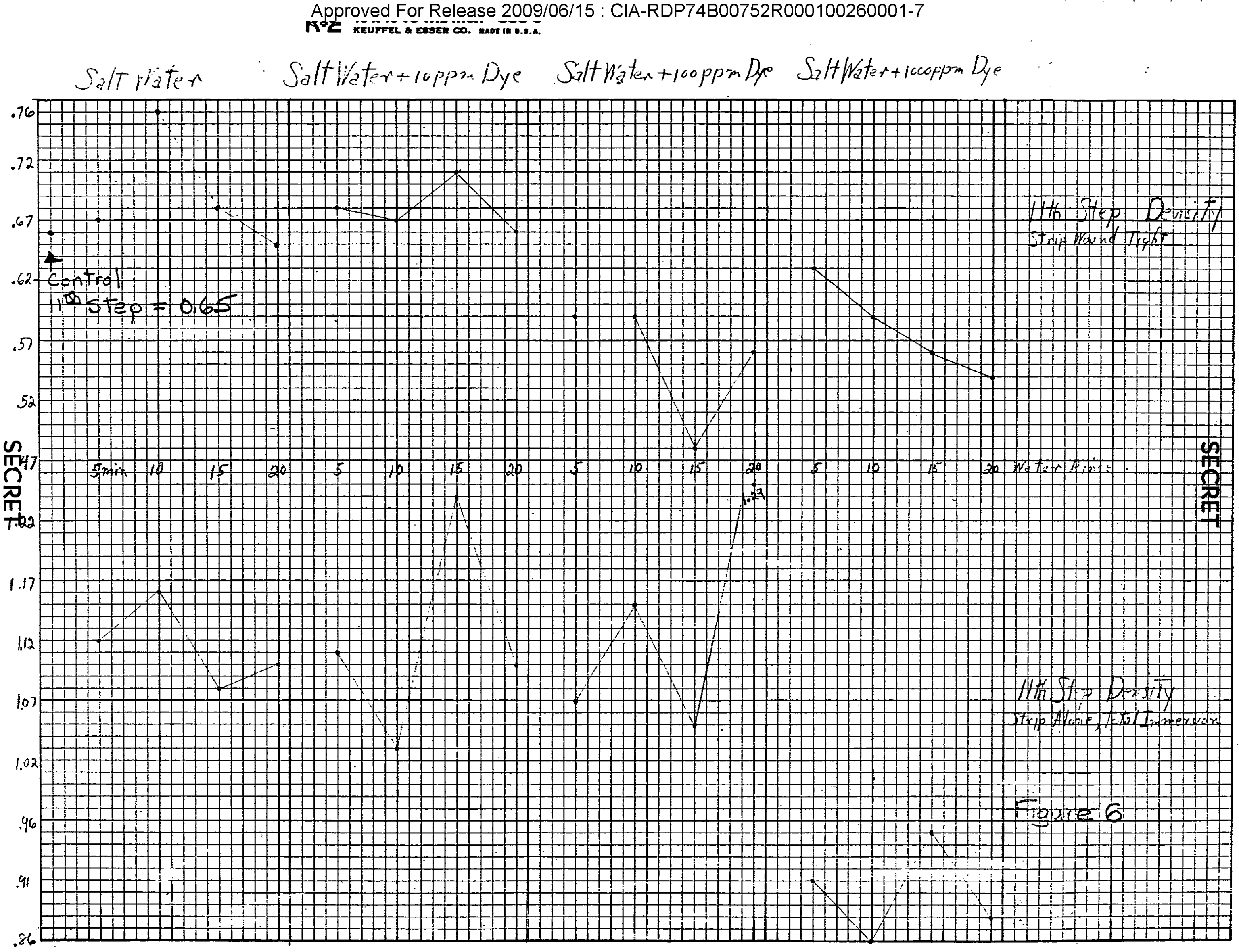
K+E KEUFFEL & ESSER CO. MADE IN U.S.A.
Salt Water
Salt Water + 10 ppm Dye
Salt Water + 100 ppm Dye
Salt Water + 1000 ppm Dye
.76
.72
.67
.62
.57
.52
.47
1.22
1.17
1.12
1.07
1.02
.96
.91
.86
Control
11th Step = 0.65
11th Step Density
Strip Wound Tight
5 min
10
15
20
Water Rinse
1.23
11th Step Density
Strip Alone, Total Immersion

Figure 6

KEUFFEL & ESSER CO. MADE IN U.S.A.

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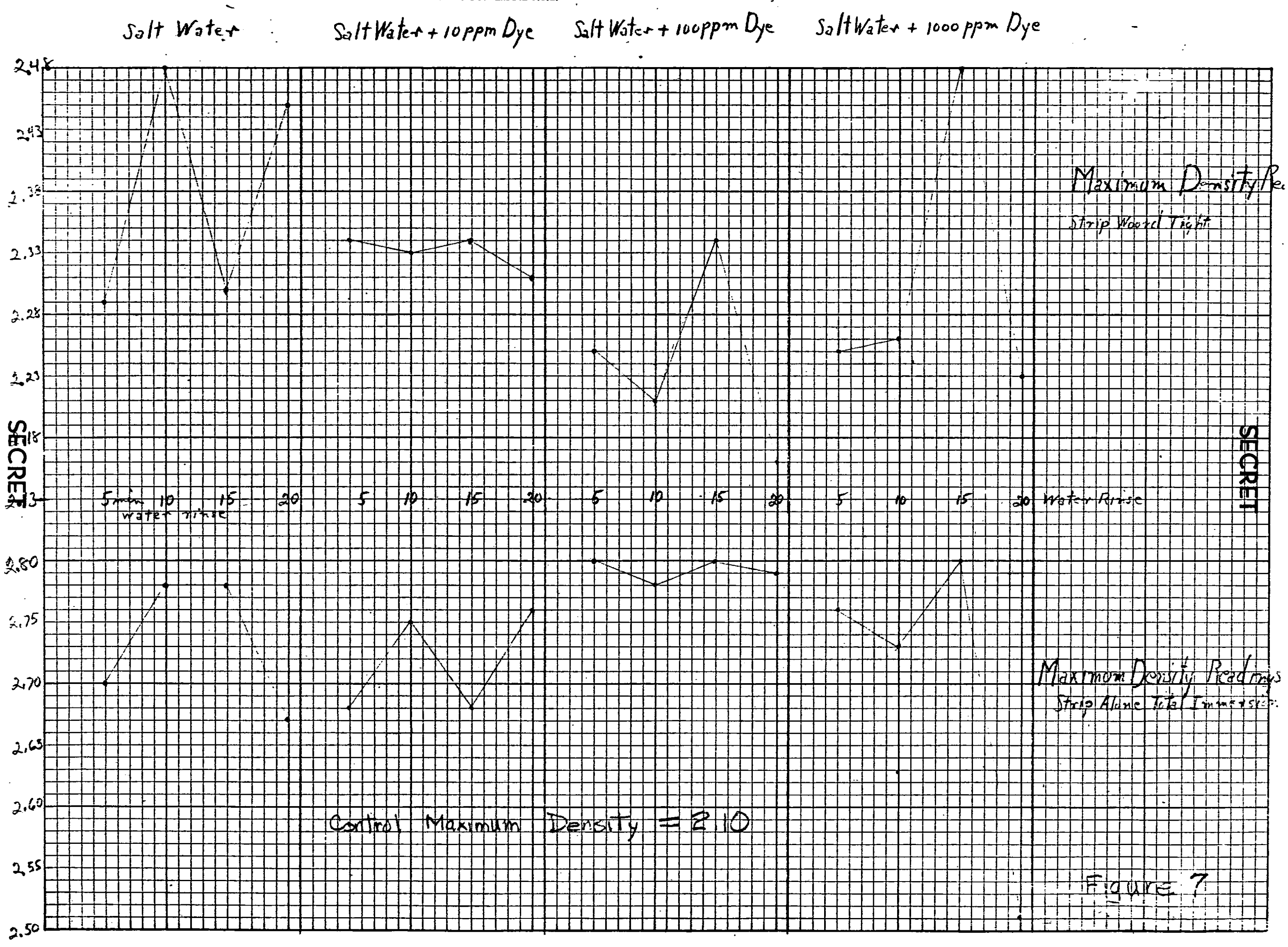

Figure 7

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Defense Products Division
Fairchild Camera and Instrument Corporation
5 Aerial Way, Syosset, New York

Report No. SME-AB-3
25 July 1958

PANORAMIC CAMERA SYSTEM FOR A SPIN-STABILIZED SATELLITE

PART II
GENERAL CAMERA DESIGN

STAT

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Program Chief

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Chief Engineer

Copy No 1

SYSTEMS MANAGEMENT AND ENGINEERING DEPARTMENT
Defense Products Division
Fairchild Camera and Instrument Corporation

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DEFENSE PRODUCTS DIVSION
Fairchild Camera and Instrument Corporation

Report No. SME-AB-3
25 July 1958

PART II

GENERAL CAMERA DESIGN

ABSTRACT

Part II of Fairchild Report SME-AB-3 is introduced by a statement of the relationship of the description of design to the general factors which were evolved from the study reported in Part I.

This introduction is followed by a description of the design of the satellite camera system complete with controls integrated with the satellite itself.

The relationship of the camera to the vehicle is first described for general orientation in conveying an understanding of the camera system. Since the whole system rests upon a foundation of optical nature the optical system is described next. Next to the optical factors mechanical considerations related to the handling and precision transport of film seem to be most prominent in the list of these factors which govern the choice of design configuration. Accurate film synchronization is a strict necessity for a high acuity rotating panoramic camera and the report devotes an appropriate space to the description of design approach to meet this requirement. In accomplishing the dynamic requirements of the system strict attention must be paid to the disturbing influences that might result from camera reaction on the vehicle itself. The measures that can be taken to balance or compensate these disturbances are described.

It is necessary to control the exposure time of the camera and a programming of exposure control is described.

A major item in the camera system itself remaining to be described is the recoverable cassette which is designed for controlled re-entry.

Test equipment for pre-flight check-out is described finally. A special collimator system for simulating flight conditions is suggested.

DEFENSE PRODUCTS DIVISION
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INTRODUCTION

Part I of SME-AB-3 has been devoted to an analysis of the factors which influence the design of the camera system. These factors are determined largely by the use of a spin-stabilized satellite as the vehicle and also the source of control for the camera system operation. It has been shown not only what the optical parameters must be to achieve required acuity, but also what mechanical tolerances in film synchronism and image motion compensation must be achieved to retain this potential acuity in the end product of the system.

How to achieve these tolerances in practice and yet stay within the limitations imposed by the vehicle configuration and weight capacity is the subject of this part of the report.

Fairchild's recommendation is to use SO-1213 film to fulfill the major portion of the operational mission requirements. This film, or equivalent, processed to give direct positive transparencies should furnish the best medium for photo-interpretation.

Recent laboratory tests have confirmed that this, or equivalent film can be used at an ASA rating of 40 to 80, permitting the use of relatively high shutter speeds resulting in a high order of detail in the reconnaissance information.

The ground-based system for processing the film output and the photogrammetric system for extracting accurate location data from the satellite photography are within the sphere of Fairchild's interests and proficiencies. Reports and proposals are available from Fairchild on these ground-based systems. However these documents are not included with this report.

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DESCRIPTION OF GENERAL CAMERA DESIGN

A. Relationship to Vehicle -

The camera design, as shown in drawing 951L73 occupies an area at one end of the vehicle. This section contains the optical system; film handling mechanism; film supply and mechanism & control components. The entire camera bolts to the internal framework of the vehicle and utilizes the outer shell of the vehicle as the necessary light proof container for the camera. The film take-up cassette is located at the other end of the vehicle as a portion of the recoverable data capsule. The camera is dependent upon power supply and photographic command signals from the vehicle's system components.

B. Optical System

Detailed construction of the optical portion of the camera can be seen on drawing 951L62. The Spica Corp 24" focal length f/5.0 lens is located directly behind the vehicle window with light baffling at the window - lens connection. All the entering light is thus confined to the light tight optical compartment which begins at the vehicle window and terminates at the film focal plane. The lens is secured to the camera proper by means of a lens cone. The optical path is then folded 90°, by a fixed front surface mirror, to the scan sprocket. The focal plane of this system lies on the periphery of the cylindrical scan sprocket. The focal plane shutter or slit is located directly in front of the scan sprocket so that the film passes between these two elements.

The lens system is focused by means of a focusing ring located between the lens and lens cone. Controlling the thickness of this ring will compensate for a varying flange focal distance variation on the order of ±.090". Accurate machining of the mirror seat to an accuracy of 5 minutes will be sufficient to seat a fixed mirror without necessity for adjustment, the depth of focus of the lens compensating for the slight error in location of the reflecting surfact. The focal plane slit can be nominally set at a 1/4000 second exposure time. The slit width is a function of the spin velocity of the vehicle and the lens focal length. The scan rate of the vehicle, w = 25.0 rpm or 2.62 radians/sec., dictates the film velocity during photography, V = w x F.L. = 2.62 x 24 = 62.8"/sec. The slit width, s, would therefore be v x t = 62.8 x 1/4000 = .0157". Variation in focal length of the lens can be held by the lens manufacturer to ±.010 inch on the 24 inch nominal focal length. This change in focal length will actually add in to the photographic system as a velocity error, however the magnitude of this error would be 0.04% maximum.

It will be noted on drawing 951L62 that the optical axis has been set off center by .052" from the center of the film. This has been done to set the format off the center of the film and allow approximately .1 inch, along the edge of the film and immediately outside the format, for purposes of data recording.

The lens proposed for use with this system is a 24 inch f/5.0 lens manufactured by the Spica Corporation. This is an aspherized version of the present 24" telephoto lens presently in use, containing the same 7 element main cell and the field lens doublet located near the focal plane. The alteration in curvature will provide an AWAR of 100 lines/mm on SO-1213 Eastman Kodak film. The weight of this system in light weight barrels would be 9.5 lbs. It is ideally suited for the compact space configuration under consideration. Optimum performance will be obtained with the use of a minus blue filter which can be incorporated with the field lens. This modified lens can be made available in the short term delivery program under consideration. This choice was made on the basis of an overall balance of maximum quality, minimum bulk and weight and availability considerations.

Photographic tests have been made by Fairchild on a sample of this lens. Table I presents the linearly averaged resolutions obtained over a 10° slit.

TABLE I

Film	Resolution * with Medium Control Target
Eastman SO-1213	100
Eastman Super XX	50
Eastman Aerecon Plus X	58

* Because of the time limitations it was not possible to obtain sufficient data to determine maximum resolutions for each lens-film-target combination.

These tests were made using targets illuminated with white light filtered through a minus blue filter conducted in accordance with method 7 of MIL-STD-150.

As noted in Table I, maximum resolution for each lens-film-target combination were not determined. An increase in recorded resolution can be obtained by increasing film contrast during processing, particularly for the low contrast targets. The degree of improvement will increase with increasing contrast control available in the film. The anticipated degree of resolution improvement possible with the three films tested will vary in the order:

greatest - Aerecon Plus X, second - SO-1213 and, least, Super XX.

Although the Spica lens is being proposed for the first units, a parallel program will be carried on to develop a more elegant design, capable of producing image qualities high enough to make the information content on the film essentially limited by the emulsion. Of the various solutions we have been able to investigate, the most promising appears to be a modification by the Perkin-Elmer Corporation of a design developed by Dr. J. G. Baker. This design at f/2.8 is expected to give a minimum resolution across the 4-1/2 inch slit. However, it would be unrealistic to expect a lens representative of the design capability to be ready in time for the first units. There is a lead time of three to four months on delivery of the glass and the design involves the use of accurate aspheric surfaces which are notorious for requiring a longer than usual amount of recomputation and refiguring of surfaces before a good sample lens is available. It is considered advisable that the new lenses be phased in to the studied program just as soon as they become available.

The lens philosophy discussed above has been discussed with and agreed upon by Dr. J. G. Baker.

C. Film Capacity

The film capacity required for this camera can be developed from the basic design parameters. An angular coverage of 93° with a 24" focal length lens will give an active format length of 39.0 inches. We can assume a wanted film length of one inch, per frame, for acceleration and deceleration of our scan mechanism from our previous experience with panoramic cameras. For 36 minutes of photography a cycling rate of 1 frame for every 4.8 seconds would require a total of

1500 feet of film. An additional 25 feet of film would be used for camera loading and pre-flight check-out purposes so that a total of 1525 feet of film would be required. The camera design will be based on the use of standard base film.

D. Film Handling

1. The technique of handling film in the camera design makes use of previously established methods used in panoramic camera designs. Perforated 5 inch film was found to track reliably under scan and transport velocities of a higher order than presently under consideration. The major design effort has been based upon the use of perforated film. However, at the present time the availability of a thin base (either acetate or mylar) film in perforated for, in the short time allotted for this program, is under investigation. The use of non-perforated film is also under consideration, and although it is felt that the desired reliability and performance can be achieved, the design as initially anticipated would involve a more complicated film handling mechanism.

Details of the camera's film handling mechanism can be seen on drawing 951L73. The unexposed 5" perforated film is mounted on a spool directly behind the scan sprocket. The film is drawn off this supply spool by a 14 tooth supply sprocket and fed into a supply chamber. The film accumulates in this chamber in uncontrolled loops until an amount sufficient for one camera cycle of 40.0 inches has been introduced. The supply sprocket rotation will stop, by virtue of a de-clutching and braking mechanism, and the full supply spool will be braked to a stop by a permanent magnet hysterisis brake. Scanning and photography then takes place by rotation of the scan sprocket at a constant synchronous speed which passes the film by the focal plane slit exposing it and depositing it into the take-up chamber in a loose loop formation. Completion of this scanning action immediately starts the film supply sprocket rotation. Acting in conjunction with the supply sprocket, and on a 1:1 basis, the 14 tooth take-up sprocket withdraws film from the take-up chamber depleting the amount of film left in that area by the 40.0 inches or the same amount that is immediately supplied to the supply chamber. The film path from the take-up sprocket continues through a long narrow chamber as shown on drawing 951L73 to another 14 tooth hold-back sprocket. The function of this second feed sprocket is to act as an aid in film handling over this long length in addition to providing a reaction member, with a non-reversible mechanical drive, for the cassette take-up motor. This worm-driven sprocket eliminates any mechanical feedback by the take-up motor into the basic film drive system which may cause a disturbance in this speed servoed system. The take-up cassette removes the film supplied by the hold-back sprocket storing it on a take-up spool. A further discussion of details of the cassette will appear in a later section.

Design of the film handling mechanism using non-perforated film would involve a change over from the previously described sprocket drives to roller drives. The film paths described would also be applicable however it would be necessary to add loop forming shuttle rollers in the film chambers to control the amount of film metered for each cycle. These rollers would also serve to form a controlled film path in the supply and take-up chambers assuring film handling reliability. A preliminary design of such a system can be seen on drawing 951L72.

The space configuration utilized for the mechanism and control section of the camera can be seen on drawing 951L73. The basic space consideration of this area was delegated by the mechanism involved. However space location as shown was not chosen for compactness of camera design, as is normally the case, but by desired location of camera and vehicle C.G. The film drive mechanism offsets the unbalance caused by the lens and cone combination so that the center of gravity of the camera will be located on the spin axis of the vehicle.

E. Film Drive

Referring to drawing 951SD2 the basic elements of the film drive mechanism can be seen. The prime-mover of this system is a continuously running speed servoed film drive motor. The synchronous speed of this motor would be 10,080 rpm for the theoretically correct 25 rpm of the vehicle. This motor drive properly geared is transmitted to the film handling sprockets by way of electromagnetic brake-clutches which actuate in proper sequency as delegated by the camera control section. The basic timing, due to vehicle rotation, requires one complete cycle for the camera every 4.8 secs. As noted on the timing diagram; 3.9 seconds of this time has been apportioned to film take-up and supply. A 125 second delay between end of supply and scanning and a .65 second scan time for photography. The 3.9 second transport time for the 40.0" film per photograph allows a slow feed and take-up rotation so that film will move at the rate of 10.3 inches/second. The .25 second delay after this transport insures the camera operating with the proper amount of supplied film for a scan in addition to allowing any induced disturbances or vibrations to be damped out prior to photography.

The total motions of the scan sprocket and the feed and take-up sprockets are geared over to a film feed "brain" shaft. This shaft rotates 180° per camera cycling and is a simple follow up device controlling the actuation of the sprocket clutches L7 and L9 by energizing and de-energizing switch S-9. This "brain" switch, it can be seen, "gates" the clutch operating pulses coming from the scan relay K-6 which in turn is energized by the mechanical control section of the camera. The important function of this mechanical follow up is to assure the camera scanning only when there is sufficient film in the supply chamber for a photograph.

Actual design details of the film drive mechanism can be seen on drawing 951L14. The entire gear train including clutches and film motor has been designed for the conditions as indicated on drawing 951SD2. Further details on design of the film drive can also be seen on drawing 951C15 and 951C23 which are complete layouts of a breadboard of this system. Here again the entire drive from the motor to the appropriate film handling sprockets has been designed to test out the actual design parameters.

An engineering analysis of the film drive errors to be anticipated in this design has been made in order to determine its magnitude and its effect upon image degradation. The film drive mechanism will contribute a scan velocity error of 0.2%. This error is a summation of gearing, mechanical wind up and velocity loss in the motor due to sudden load application.

The film drive gearing from the film drive motor to the scan sprocket must be of high accuracy in order to transmit velocity linearly. Any errors in eccentricity or tooth profile will cause a velocity ripple in transmission during photography. The use of A.G.M.A. Precision Class 3 gearing, A.B.E.C. Class 7 bearings and a limit of .0002 inch T.I.R. on eccentricity of locating diameters will limit the maximum r.m.s. velocity error to .06%.

The sudden load application of the scan clutch, during the acceleration period of the scan sprocket will cause a torsional deflection, θ, in the shafts transmitting this acceleration torque, Ta. Upon reaching a constant velocity this deflection will be released and cause a velocity variation as a function of the deflection and natural frequency of the system. Since $\theta = Ta/K$ where K is the spring constant of the system then the velocity error, $\Delta \omega = \theta \omega_n \cos \omega_n t$. The velocity error in this system is $\Delta \omega / \omega = .07\%$.

The sudden load application of the scan clutch will also cause a loss in motor speed due to an energy transfer in the film drive system. This speed change will exist at the beginning of the photographic cycle and constitute a velocity error prior to the speed servo correction. Considering the motor as a flywheel with a known kinetic energy, $1/2\ I_1 \omega_1^2$, the introduction of the intermittent scan drive will be an additional inertia load giving a new speed ω_2. Solving the equation:

$$\frac{1}{2}\ I_1 \omega_1^2 = \frac{1}{2}\ I_2 \omega_2^2 + \text{losses.}$$

$$\frac{\omega_1 - \omega_2}{\omega_1} = .07\%.$$

The total errors considered, a maximum of 0.2%, are well within the allowable velocity variation in the film transport mechanism.

In order to compensate for image motion due to forward motion of the vehicle the film plane should be moved in the direction of flight. In a panoramic camera the most practical way of achieving this is to tilt the focal plane roller the proper amount and utilize a vector component of the film velocity for image motion compensation. By building a fixed average tilt angle of the focal plane into the camera the "blur" due to image motion can be reduced by approximately 85%. This average compensation angle will be approximately 39 minutes of arc. The maximum blur will be reduced to .00013 inches at an exposure time of 1/1000 sec.

Also under consideration is a method to achieve proper image motion for all values of the scan-angle. This can be done by the inclusion of a harmonic motion linkage mechanism. In view of the projected short development time for this camera the complications resulting from the addition of this mechanism may be such as to preclude its inclusion in the camera. Since the image motion compensation is very small the mechanism might introduce "blurs" of larger magnitude than the ones produced by the image motion due to linkage defledtions and back-lash.

No attempt is made to vary the image motion compensation with varying altitude and forward velocity. Such a system would necessitate a constant monitoring and computing and would complicate the system unduly. Furthermore the operational requirements are for a constant speed and altitude.

From the above analysis it can be seen that the optical spin axis must be known to very close angular tolerances so that the film scan axis can be aligned properly within the vehicle. In order to obtain an image motion compensation as outlined above the alignment should have a tolerance of about 5 minutes of arc. This calls for mounting provisions on the vehicle and on the camera to close mechanical tolerances to their respective axes.

The vehicle will spin around the axis of minimum inertia. This axis must be established and maintained during flight. As described in Section D, the film spools are placed in the vehicle in such a way that the film shift occurs along this inertial axis and no film-balancing weights are required.

A design of the film drive motor speed control system, making use of Zener diodes as a reference voltage and obtaining a variable output from a DC tachometer driven by the film motor, is shown on drawing No. 951SD4. A DC error signal is delivered to a silicon diode ring bridge modulator electronic chopper which converts the DC to AC. The AC is amplified in three stage transistorized amplifier and then rectified in a phase sensitive detector. The DC current derived is used to alternately increase and decrease the flux of an auxiliary field winding of the film motor and hence maintain the speed of the film motor constant. The system is capable of varying the motor speed approximately ±10% from a nominal value of 10,000 rpm. The design was based on specification accuracies of ±.5% in speed stability over the environmental conditions previously outlined. Power for the amplifier is obtained from a 28V DC source, while the drive for the chopper and the required AC reference phase voltage is obtained from the 400 cycle timing amplifier discussed above.

F. Camera Reactions

1. Torque Effects

In order not to affect the angular momentum of the vehicle it is necessary that the camera proper not deliver any torque to the vehicle as a consequence of the angular acceleration and deceleration of the film transport mechanism. A simple and expeditious way of accomplishing this is by having the net vector angular monemtum of the rotating parts of the camera vanish under all modes of operation. Thus, for example, if we choose a special direction, the angular momentum of the clockwise rotating members must be equal (and opposite) to the angular momentum of the counter-clockwise rotating members. It is, of course, necessary to judiciously choose the configuration such that the above requirement is fulfilled without the addition of appreciable extra weight. It should be noted that having zero net angular momentum at any speed of geared components assures that the momentum vanishes at all speeds. Experimentally, or in fact even as a pre-flight check, if necessary, the accuracy with which this has been accomplished can be determined by supporting the camera on bearings or on a torsion wire and noting the reaction on start-up.

2. Thrust Effects

The only linear momentum associated with the camera is caused by the motion of the film and the associated counter-balancing weight. If the center of gravity of these two is on the average at the center of gravity of the craft, then the only resulting thrust will be a periodic one caused by acceleration and deceleration of the film alone. The average of the periodic thrust is also zero. If this thrust passes through the center of gravity of the craft, it produces a small pertubation in its linear velocity. This velocity pertubation can be obtained from the conservation of momentum $(m_1 v_1 = m_2 v_2)$.

Craft weight 300 pounds assumed
Film in transport 6 feet = .05 lbs.
Film velocity 5.2 ft/sec

$$v_1 = \frac{m_2 v_2}{m_1} = \frac{.05}{300} \times 5.2 = 8.3 \times 10^{-4} \text{ ft/sec.}$$

which is completely negligible. If the thrust does not have zero moment arm but is one foot from the C. G., it will cause an angular velocity change, which can be obtained from the conservation of angular momentum. Assuming the moment of intertia of the craft to be 150 lb. ft.^{2}, the peak change in angular velocity is as follows:

$$W = \frac{.05 \text{ lbs.} \times 5.2 \text{ ft.} \times 1 \text{ ft.}}{150 \text{ lbs. ft.}^2 \text{ sec.}} = 1.7 \times 10^{-4} \ \frac{\text{Radians}}{\text{sec}}$$

This too is thoroughly negligible.

3. Dynamic Balance of Film Spools

A summation of momentums of both supply and take-up spools during the transfer of a complete roll of film has been calculated. Inertias and angular velocities (for units as illustrated in F.C.I. layouts 951L73 and 952L7) with resultant momentums are shown in Table II and plotted on graph 951L61.

Graph 951L61 shows the resultant I ω for spools with both similar and opposite directions or rotation. Balance may be accomplished by counter rotation of a mass of equivalent I ω.

Three possible methods of controlling a variable counter momentum are indicated in drawings 951L19, 951L20 and 951L21. The methods illustrated in drawings 951L19 and 951L20 could be made to correct for either the same or opposite directions of spool rotation. Commercial units are available for all 3 applications.

Drawing 951L19 shows the ball integration system with the output rpm's determined by the position of the ball from the center shaft. Output rotation may be reversed by moving the balls from left of center to right of center of the drive disk.

Drawing 95L120 shows two (2) hysteresis clutches geared together. Output direction and speed is controlled by applying a varying programmed voltage to either clutch.

Drawing 951L21 shows a commercial metron in which the rotation is controlled by a sensing arm resting on the film which moves a programmed cam and follower to actuate the reduction ratio of the variable speed drive. This can only be used if the spools rotate in the same direction.

On the basis of the data supplied here and regardless of which of the above systems is chosen, a dynamic counter balance of film spool momentums can be developed for either similar or opposite direction of spool rotations.

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TABLE II

Momentums for 2-1/8 Core Aluminum Spool (Supply)

Film Radius on Core	Feet of Film	Inertia for Film and Spool	Angular Velocity	Resultant Momentum
4.68	1500	.4635	2.08	.963
4.25	1220	.3255	2.29	.745
4	1070	.2635	2.44	.643
3.5	800	.1710	2.78	.475
3	565	.1110	3.25	.361
2.5	364	.0717	3.90	.279
2	200	.0511	4.88	.250
1.5	76.5	.0421	6.5	.274
1.0625	0	.0305	9.18	.354

FOR L" CORE (MAG & AL) TAKE-UP SPOOL

0.5	0	.0139	19.50	.271
1	54	.0147	9.75	.143
1.5	144	.0183	6.5	.119
2	272	.0281	4.88	.137
2.5	435	.0493	3.9	.192
3	630	.0849	3.25	.276
3.5	890	.1499	2.78	.417
4	1140	.2419	2.44	.590
4.25	1290	.3039	2.29	.695
4.5	1500	.3919	2.17	.850

G. Horizon-Sensing Attitude System

One Nadir-recording system investigated consisted of a secondary wide-angle lens taking a photograph of the whole globe at a time reference to the film advance. By examining the circle of the globe in referenced to camera fiducial marks the attitude of the vehicle at the time of this secondary exposure could be established. Since the panoramic exposure will be taken every third revolution of the vehicle, the globe photograph could be taken during a non-photographic scan and be recorded in the margin between panoramic photographs. The lens angle to cover the globe has to be larger than 152° for an average altitude of the vehicle. A single lens with such a coverage angle would be quite large even for an 1 inch square photograph. A combination of smaller lenses and prisms could be used to obtain four segments of the horizon. Such a system would establish the nadir in both directions and could be also used to establish the "H" value. The drawback of the system is the complexity of the optical path, especially since no optical "dome" protruding beyond the skin of the vehicle can be tolerated. Also such a system would not contribute to the solution of the problem of starting the photographic scan at proper attitude.

Another method of establishing the nadir in the direction of flight on the photograph involves the use of two photocells and two recording lamps. The lamps will be symmetrically located on either side of the exposure slit. The photocells will be symmetrically located about the lens at an included angle of 150° 30' which is equal to the angle from horizon to horizon at 135 mile attitude. As the vehicle rotates through one revolution the photocell leading the lens will be set up to trigger its recording lamp when the cell has completed scanning the earth and reaches the horizon. The photocell trailing the lens will be set up to trigger its lamp when the cell scan has completed scanning space and reaches the horizon. The midpoint between the two recordings on the film can be determined graphically and this will locate the nadir in the direction of flight.

A third system consists of a single photocell pickup of the horizon. The cell will generate a voltage when the scan reaches the horizon and will maintain this voltage until it passes the opposite horizon. It will be easy to differentiate this voltage-pulse from the one generated by the passage over the sun-surface since its time duration will be considerably larger. The time-duration of the earth-horizon pulse will vary with altitude and attitude, but it will always be summetrical to the nadir in the spin-plane. A mechanism used to divide this pulse (corresponding to an angle) symmetrically in two, and to record it in the photograph is described the following paragraphs. The same mechanism will subtract an angle of 46-1/2° from the nadir and provide the starting pulse to the film transport mechanism.

The horizon-sensing system described above does not provide nadir information in the flight direction, but it is felt that such information could be obtained from the examination of the photographs, since the maximum "pitch" of the vehicle should not exceed 20° and, as outlined above, an error of 5° would result in a scale factor error equivalent to a distance error of approximately 2 miles between two points on the one frame. Since the time base is recorded on the photograph, and the vehicle speed is known accurately, the distance between any two points recorded during one orbit pass can be calculated to the accuracy of 2 x 1.5 = 3 miles.

No recording of the altitude of the vehicle is contemplated at this time. Such information will have to be obtained from orbit observations.

At present it is contemplated to obtain the rotational spin of the vehicle by means of an electric motor. While it is felt that such a spin-system will be able to control the spin rate to close tolerances, variations in inertias of the vehicle and pos and of the motor might result in spin variations in excess of 1%. As outlined above a synchronization of the film drive to the spin-rate must be maintained to an accuracy of 5% in order to obtain high resolution photographs. Thus it is contemplated to slave the film-drive to the spin of the vehicle by means of velocity-position servo system. The photo-cell horizon-sensing described above and used for nadir recording has also been adopted as command for the film-drive servo-system.

The control section of the camera performs the function of properly controlling the actions of the camera. These functions include speed sensing of the vehicle and servoing the film drive motor to a synchronous speed; attitude sensing and programming the camera scan angle correctly for a vehicle rotation; sequencing of data recording and computing a nadir for data interpretation. The camera control system utilizes the horizon sensor.

Drawing 951SD2 shows the control section of the camera schematically. The fundamental item in this mechanism is a one revolution shaft rotating at a speed synchronous to the vehicle speed or 25 rpm. This shaft has a fixed relationship to a point on the camera frame such that the commutator SI is at the same orientation whenever the horizon is sensed. This in effect establishes an artificial horizon in the control section and is noted as 1 rev. shaft - horizon oriented.

The horizon 1 rev. shaft is oriented by means of the horizon phase correction shaft. Since there is no established orientation of the horizon shaft between receipt of camera command pulses, (These camera command pulses are received from the system's programmer at command relay K3). this pulse may stop and start the camera again with a misphased horizon shaft. The correction shaft will sense the amount of misphasing, retain it as a memory device and then either add or subtract a phase angle to eliminate the error. The correction shaft is, in effect, a secondary 1 rev. shaft running at the same speed as the horizon shaft and phased correctly to it by means of the synchronous "brain" interconnecting shaft. The receipt of a horizon pulse of controlled duration at the commutator, S-1, when the shaft is misphased will cause the follow-up clutch, L-2, to disengage and lock this angular information into the correction shaft. Engagement of the bidirectional slewing clutch L-1 will start a correction into both shfats through differentials D1 and D3. The same phase angle will be added or subtracted on both shafts equal to the original misphasing from the horizon of the horizon 1 rev. shaft.

The horizon correction shaft will bring the one revolution shaft into approximate registration thereby correcting a large error in misphasing. Speed regulation of the servo motor will be obtained by utilizing the displacement correction given to the horizon one revolution shaft. Since the commutator on this shaft will be out of registry with the horizon pulse only due to a velocity error in the system, the displacement correction is proportional to this error. As shown on drawing 951SD2 the servo potentiometer is positioned by the correction shaft thereby controlling the command to the film servo motor. This system will continuously correct the horizon shaft with a displacement and velocity change after each revolution until it is in registration with the horizon pulse.

The horizon shaft can now be used as an input to differential D2 with a phase correction angle B as a second input to now give a vertically oriented shaft. Since the angle B, referring to drawing 951L65, is a variable angle, dependent upon the attitude and altitude of the vehicle it is necessary to sense this quantity and subtract it from the artificial horizon. The receipt of a horizon pulse, equal to a horizon to horizon scan or angle 2B can actuate a half speed clutch L-3 and add the phase correction equivalent to angle B to the vertical oriented shaft. This shaft will give us proper scan sequencing by actuation of switch S-3, data recording of time and nadir indication on film.

The control system described is one system that has been considered as a solution to the problem. A preliminary engineering analysis indicates that the time constants of various mechanical components may limit the accuracy of the system. A complete engineering analysis must be conducted in order to determine if the limitations are such as to prevent the computation of the required data to the accuracy desired. Other designs for this section have been devised in order to produce an equivalent functioning system. A description of such another design follows.

It is the function of this system to maintain the speed of the "one rev. shaft" in the camera at the same value as the "spin up" speed of the vehicle and to "time" the shaft so that it is in a particular "registry" position at the instant of receiving the "on terrain" pulse from the horizon sensor.

The control system is as shown in drawing 951SD8. It consists of a basic velocity servo loop containing a DC command signal potentiometer, servo amplifier, drive motor, and feedback tachometer generator. The command signal potentiometer has sufficient range to cover the range of vehicle "spin up" speeds.

At initial starting, the system operates by measuring the angular deviation of the shaft from its registry position at the time of receipt of the horizon pulse and injecting this quantity into the velocity servo system. This causes a change in speed of the film drive motor of sufficient magnitude and duration to advance or retard the one rev. shaft to bring it into approximate registry. Simultaneously the system makes a small velocity correction by changing the command signal to the velocity servo loop. This process is repeated each vehicle revolution until the one rev. shaft is continuously rotating at the same speed as the vehicle, and no fast advance or retard of the one rev shaft phasing is required.

Specifically these functions are accomplished as follows:

The horizon sensor as shown in Figure 951SD8 derives a signal from both horizons as the vehicle spins. The signals are transmitted to the horizon pulse discriminator which selects the "on terrain" pulse and transmits it to the shaft error pulse generators. These devices are also supplied with pulses from the one rev. shaft registry commutators. If the one rev. shaft is retarded in phase, the "raise" pulse generator emits a pulse which has a duration equal to the "shaft error" time interval between receipt of the horizon pulse and the arrival of the shaft at its registry position. If the one rev. shaft is advanced in phase, the "lower" pulse generator emites a pulse which has a duration equal to the time interval between the arrival of the shaft at its registry position and the time of receipt of the horizon pulse.

The raise or lower pulse is transmitted to respective raise or lower gating circuits which are also supplied with a signal from the tachometer generator. In the case of the "raise" gate, the tachometer voltage is inverted to maintain the proper correction polarities. The raise or lower gate transmits the tachometer signal to an integrating circuit which integrates the velocity signal for the "shaft error" time interval described above and produces an analog voltage proportional to the shaft error at the time of receipt of the horizon pulse.

This voltageis inserted into the integrating input to the velocity servo amplifier and changes the motor speed in the appropriate direction to start to correct the shaft error. As the motor changes in speed, the deviation in motor speed from its normal value, as determined by the voltage at the velocity summing point, is applied to the integrating summing network and starts to "null out" the shaft error signal. At the end of the shaft error pulse, the integrator continues to control motor velocity until the shaft error signal is completely nulled out by the integrated velocity deviation signal. When this occurs, the one rev. shaft has been advanced or retarded by an amount equal to the original shaft error existing at the time of receipt of the horizon pulse. The drive has in effect become a position servo during this period.

Simultaneously the raise or lower signal from the shaft error pulse generator is applied to respective raise or lower pulse generators which jog the motor operated command signal potentiometer and raise or lower the base velocity maintained by the velocity servo. This process is repeated each vehicle revolution until the potentiometer is positioned at a value which maintains one rev. shaft speed precisely at the vehicle speed. In this equilibrium condition the shaft will always be in its registry position at the instant of receipt of the horizon pulse.

As speed changes tend to take place due to variation in camera load or power supply voltage, small corrections in shaft speed are made in order to maintain precise synchronization of the one rev. shaft with the horizon pulse.

With each successive pass over the objective the camera can be started and will have the correct shaft speed because of the "memory storage" features embodied in the command signal potentiometer which does not change position between passes. The system has merely to make the coarse "shaft error" correction described above, before full synchronous operation can be obtained. In this case the velocity error corrections are negligible.

The two designs presented for the control section still require further engineering effort to fully establish their merit and desirability. Evaluation as to the best design for the function to be performed, versus simplicity, weight and size would be necessary before finalizing this area.

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Fairchild Camera and Instrument Corporation

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H. Time Recording

Recording of real time during photography has been considered a necessary parameter input for photographic interpretation. An accurate knowledge of vehicle velocity, from orbital information, combined with a time base during photography will yield ground distance during a pass. If a photographic pass of 12 minutes duration were considered as a criterion, an accuracy of the time base of ±.01% would yield a maximum ground distance error of +.36 miles. Such an error would be compatible to our overall system accuracy of locating targets within a one mile limit.

It was decided to use the output of a crystal oscillator, provided by L.M.S.D. System's Components, to drive the timer unit. For a most reliable design, the device considered consists of a mechanical counter driven by a synchronous motor. Operation would start upon the receipt of an external command signal, sent at a known time, so that the indication could be referred to solar time.

The time recording system shown on drawing 951SD2 initiates a recording of real time from a basic timer command signal from an external source. This signal sent in at a known time, starts the time indicating mechanism in the camera for the duration of its flight. Details of circuit design can be seen on drawing 951SD3 and 951SD4.

This system uses inputs of a square wave pulse accurate to 1 part in 10^4 with a fundamental frequency of 400 cycles per second. A four stage transistor amplifier utilizing push pull output capable of delivering 12.5 watts of audio power, and with a reserve capacity of at least 25 watts, amplifies the fundamental timing pulses. This amplifier derives its power from a 28V DC source. The 400 cycles per second square wave is used to drive a 400 cycle hysteresis synchronous motor running at a synchronous speed of 12,000 rpm and having a torque output of 1 oz.-in. at this speed. The rotary output of the synchronous motor is used to drive a six digital rotary counter similar to those made by Veeder-Root. In addition sufficient torque is available to drive a shutter mechanism for photographing the counter. With the proper gear reduction (200:1), between the motor and counter, the counter runs at 1 rev./sec., and the last wheel of the counter then reads in tenths of a second. Storage capacity of the counter is 275 hours. The timing system was designed with the pertinent specifications of shock, vibration, temperature and accuracy in mind, and with the proper packaging the system will meet the specifications.

I. Exposure Programming

A time base programmer to control exposure time can be included in the camera. As outlined in Part I Section B the light conditions will vary greatly with the time of year and the instantaneous latitude of the vehicle. The time of year information (and possibly time of day) will be fed into the programmer prior to the launching. The latitude information will be monitored by the programmer by means of time and the anticipated orbit. The output of the programmer will vary the width of the exposure slit to conform with the anticipated illumination.

J. Recoverable Cassette

The basic requirements of the cassette which is located at one end of the vehicle are that:

1. It must be an independent unit to be encased in a re-entry sphere and capable of protecting the exposed film from high impact forces, temperature, and immersion in sea water.

2. It must be capable of storing approximately 1500 ft. of 5" wide thin base film.

3. It take up film by means of its own power source at a rate of approximately ten inches per second.

4. It must be of the least possible weight, consistent with the requirements.

5. The size of the cassette is limited by the overall size of the molded sphere.

6. 100% reliability of operation is of utmost importance.

Preliminary calculations were made to obtain the motor torque requirements, weight estimation and the types of motors available for power to take up film. A number of motors were available, in different configurations, any of which could be expected to operate satisfactorily.

Contact was made with a number of companies to ascertain what direction could be taken in the container design and it was decided that molded rubber containers offered the best possibilities to insure a light tight, water proof seal for the film after impact. Various design layouts have been made showing different configurations. As these layouts progressed, they were changed and improved until a design which appeared practical resulted. Early in the design stages it was apparent that the biggest problem area was in obtaining a satisfactory design for the film cutting device, and for sealing the opening in the container through which film passed to the spool. A number of schemes have been tried, modified, and rejected, mainly due to the lack of assurance of 100% reliability. The final selection was a design having no mechanical parts for film cutting and none for sealing. Layout 952 L-7 shows a film cutting device, in which the high pressure developed by the discharge of the cartridge, is directed theough a nozzle onto the film thereby separating it in the cassette. Should the cartridge fail to fire, a second cartridge would be exploded to perform the cutting of the film. The second cartridge will fire even though the first one operated as a further reliability precaution.

The second or lower chamber contains a viscous material. This material will be extruded into the film slot, (after film has been pulled through also by an explosive cartridge. This viscous material will be forced across the slot and form the seal. Again a back-up safety cartridge will be fired to insure sealing should the first cartridge have failed to explode.

This layout shows that a motor has been mounted outboard of the film container. This design eliminated gear trains, required for the higher torques deemed necessary, and acts as a buffer to absorb some of the initial impact forces. It will also be seen that the cassette and rubber container walls, and the film spool, are heavier on the impact side. This design will assure survival of the film intact.

This design results in increasing reliability considerably, with weight as well as complexity being reduced to a minimum. It is believed that breadboards of the film cutting and sealing devices will prove this method to be 100% reliable. The motor, film spool, rubber container and outer container should also be breadboarded. Probably a number of complete cassettes will be required to conclusively prove that the unit will operate without failure, and can survive the severe conditions of recovery anticipated.

Before final breadboard drawings are made, the companies which exhibited interest in this development and appeared to be capable of performing the required work should be again contacted to insure that they can meet the requirements of the motor and the container.

It is known that the concept of re-entry into the atmosphere and recovery of a data capsule has been fully developed by the General Electric Company. The FCI study has been directed toward the design of a film storage device to perform satisfactorily in conjunction with the operational parameters of the data capsule.

The recoverable data capsule would be detached from the vehicle upon receipt of an external command signal which would energize the recovery rocket providing the motive power for this action. An 18" diameter sphere, consisting of an oblating material already developed, will protect the unit from the extreme environments encountered during re-entry. Impact of this capsule in the predetermined recovery area will separate the oblating material from the remaining 16-1/2 inch diameter floatable sphere.

The recoverable cassette will perform the function of film take up during photography. A DC torque motor is contemplated for operating the take up spool, receiving its command signals from the camera through an electrical connector. Thus a mechanical connection to the camera is avoided, easing the capsule separation problem from the vehicle.

The last function of the cassette is withstanding the high deceleration forces without adverse affect upon the film. Orientation of the film spool in the cassette, so that the anticipated 4,000g loading will act parallel to the spool axis, will distribute this load and avoid pressure makring of the film. Distortion of the cassette film can be expected under load. However, the design will avoid this affecting the sealing device which will remain intact after impact.

K. Test Equipment

Test and check-out support will involve thorough and complete inspection and tests which will prove optimum performance of the unit and thereby insure mission success. A maintenance test area is envisioned where the unit will undergo complete inspection and test prior to installation in the vehicle. The camera will be energized with proper operational voltages and signals. Film may be threaded through the camera unit while visual and instrumented observations of the critical functions of the camera unit are made.

Final tests will be made after installation in the vehicle. Such tests will be made to conclude that successful mating with vehicle power, control signals and mechanical members have been made and that no damage has been incurred through handling and transit to the vehicle. A very precise check of the alignment of the film scan sprocket with the spin axis of the vehicle will be made at this time. The exact nature of such a test will have to await more complete liaison with the vehicle manufacturer.

For the maintenance test area, as a final check on photographic quality and camera operation before flight, a flight simulator will be furnished. The flight simulator will require that the test vehicle with installed camera be rotated on its axis, and that a combined power and monitoring cable to be attached to the camera. The simulator will consist of several collimators arranged at intervals about the periphery of the vehicle with an adjustable stand and a horizon sensor simulator. The collimators will be approximately three feet long. Each collimator will be equipped with multiple resolution targets, to provide images in various areas of the camera film.

As the vehicle is rotated the horizon will be simulated, by positioned light sources energizing the horizon sensors. As rotation continues the images from each of the collimators will be photographed, with targets placed at beginning, end and middle of each frame. All camera components will operate during this test and results will be shown on the film. At completion of the test it will be necessary to reset the mechanical timer to zero.

For the maintenance test area a console will be supplied with complete power facilities. Provision will be made for calibrated pulsed light sources to energize the horizon sensors. A test connector from the camera to console will supply feedback voltages which will be monitored to show proper operation of verticality recording shutter, scan sprocket rotation and motor speed. Actual film movement will be sensed close to the take-up spool to insure a film jam or breakage has not been caused by improper loading. This will be accomplished by either, a rotating commutator, driven by the film producing an electrical pulse or by a pin light and photocell combination also giving an electrical pulse. These pulses will be monitored at the console.

Whenever possible monitored voltages will be applied to a tape. (Such as a Sanborn recorder). If testing procedure is programmed each tape will show all discrepancies at a glance and serve as a record for all vehicles. A secondary control will be supplied in order to operate the camera while the vehicle is undergoing testing. This unit will consist of power inputs and output connectors, associated switches and indicator lights for camera operation. A temporary mounting stand will be supplied to hold the camera and components until camera is mounted in the vehicle.

It will be required for most of our testing that a test connector be available to connect through the vehicle to the camera. This will allow testing and monitoring of any function in the camera at any time up to actual flight. This connector should be sealed off prior to flight. Standard test equipment, such as electrical counters and recording devices are supplemented for test purposes. This equipment will be mounted on commercially available running gear or integrated with the overall vehicle test equipment. Consideration will be given for protective covering for operation during adverse conditions. Section 3 of MIL-M-8090 will be used as a guide in the design of mobility provisions. MIL-G-008512A (Test Equipment)specification for use with electronic equipment will be used as a guide in procuring standard test equipment and in designing supplementary special test equipment.

L. Conclusion As To Design Feasibility

The design of the camera and recoverable cassette presented in this section is a practical solution for the operational requirements set forth for this program. The basic approach, in designing these units, has been to utilize, to the fullest extent, previously proven components and techniques to assure complete reliability and proper functioning of the unit. It should be noted that it was not found necessary to make any compromises with initial design parameters in order to arrive at a practical camera design in the short time allotted for this program.

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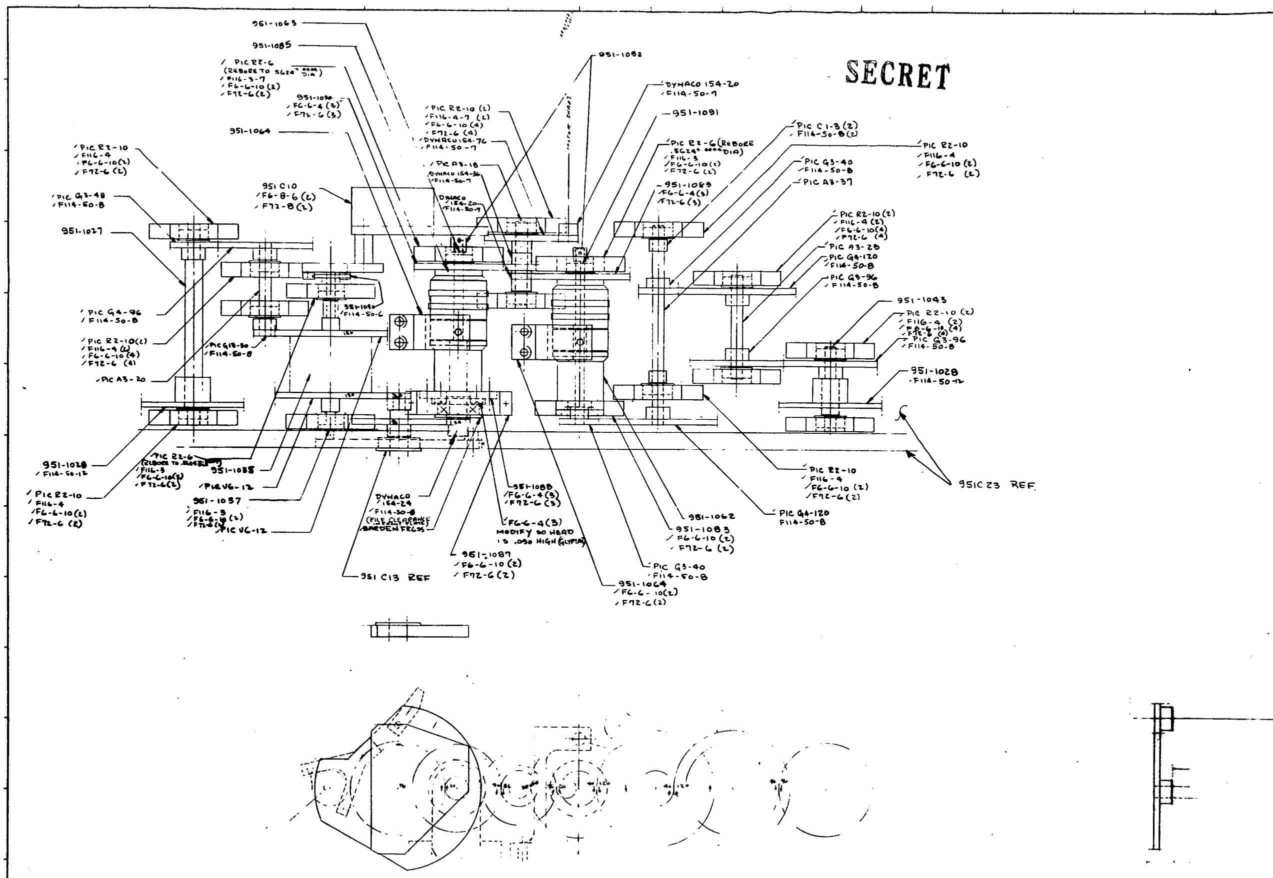

951C23		
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APPLICATION		QTY REQ'D

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

MATERIAL

HEAT TREATMENT

FINISH NO

DWN HNP DATE 6-23-58

CHKD DATE

APPROVED MATLS DATE ENGRG DATE MFG DATE DATE

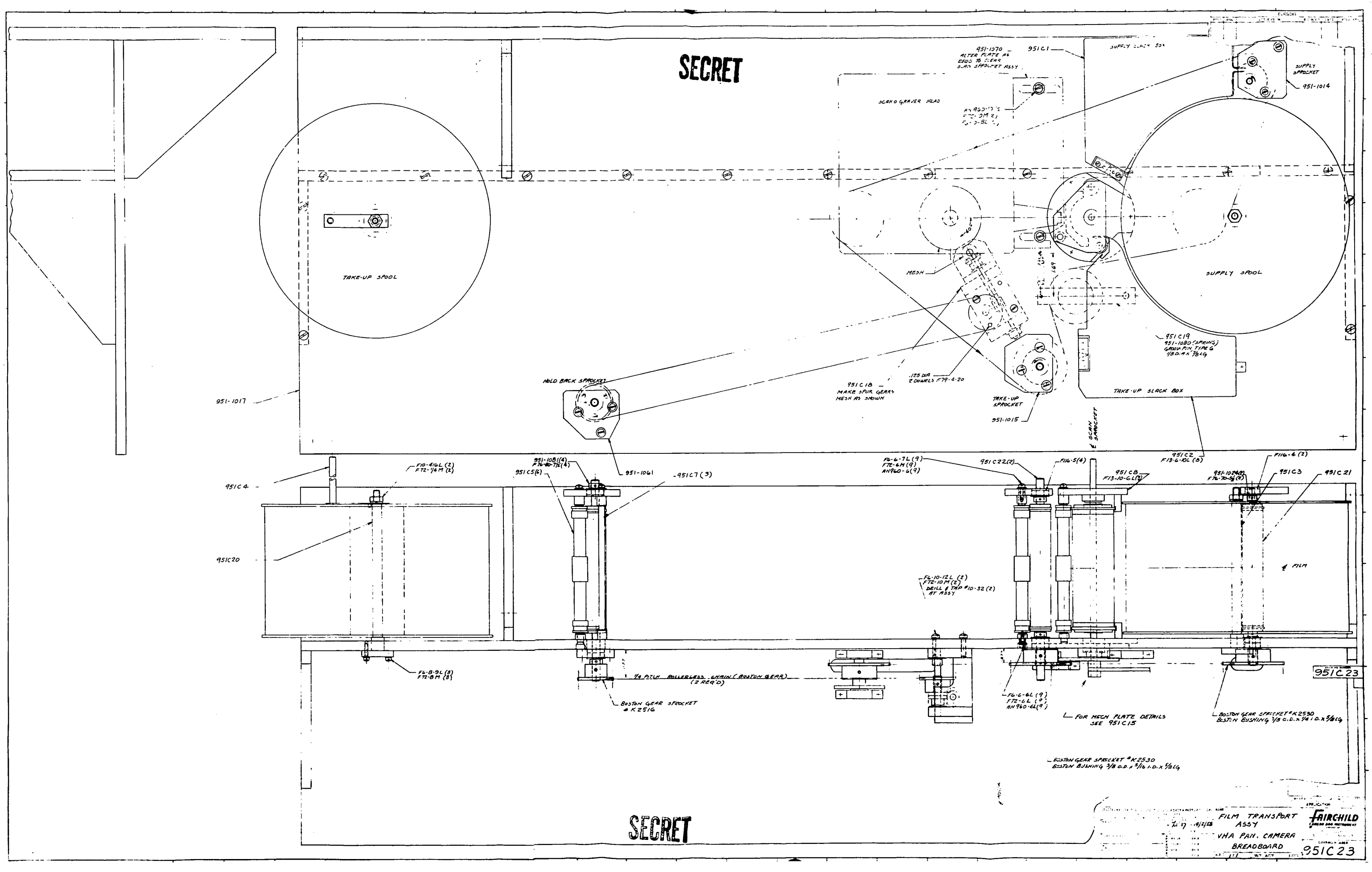
NAME: DRIVE INSTALLATION

SCALE — WT. ACT. LBS.

FAIRCHILD CAMERA AND INSTRUMENT CORPORATION
ROBBINS LANE
SYOSSET, L. I., NEW YORK

DRAWING NUMBER 951C15

SECRET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TAKE-UP SPOOL
SUPPLY SPOOL
SUPPLY SPROCKET
951-1014
HOLD BACK SPROCKET
TAKE-UP SPROCKET
951-1015
TAKE-UP SLACK BOX
951-1017
951-1061
951C7 (3)
951C4
951C20
FOR MECH PLATE DETAILS
SEE 951C15
BOSTON GEAR SPROCKET #K2530
BOSTON BUSHING 3/8 O.D. x 5/16 I.D. x 5/8 LG
BOSTON GEAR SPROCKET #K2530
BOSTON BUSHING 3/8 O.D. x 1/4 I.D. x 5/8 LG
BOSTON GEAR SPROCKET #K2516
951C23
SECRET
FILM TRANSPORT
ASSY
VHA PAN. CAMERA
BREADBOARD
FAIRCHILD
951C23

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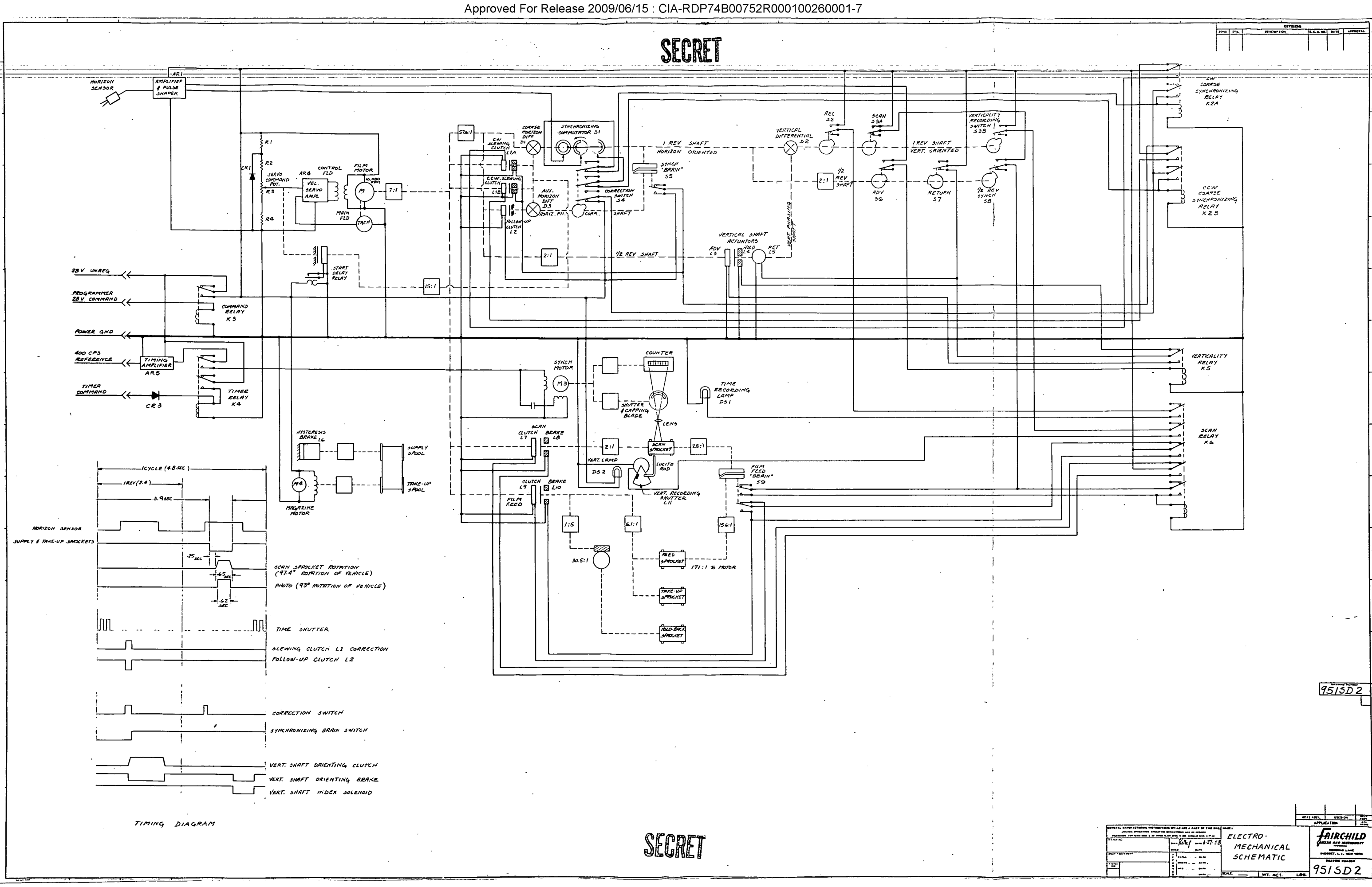

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NOTE - ALL CAPACITANCE VALUES IN MICROFARADS
ALL RESISTANCE VALUES IN OHMS

DRAWING NUMBER 951SD3

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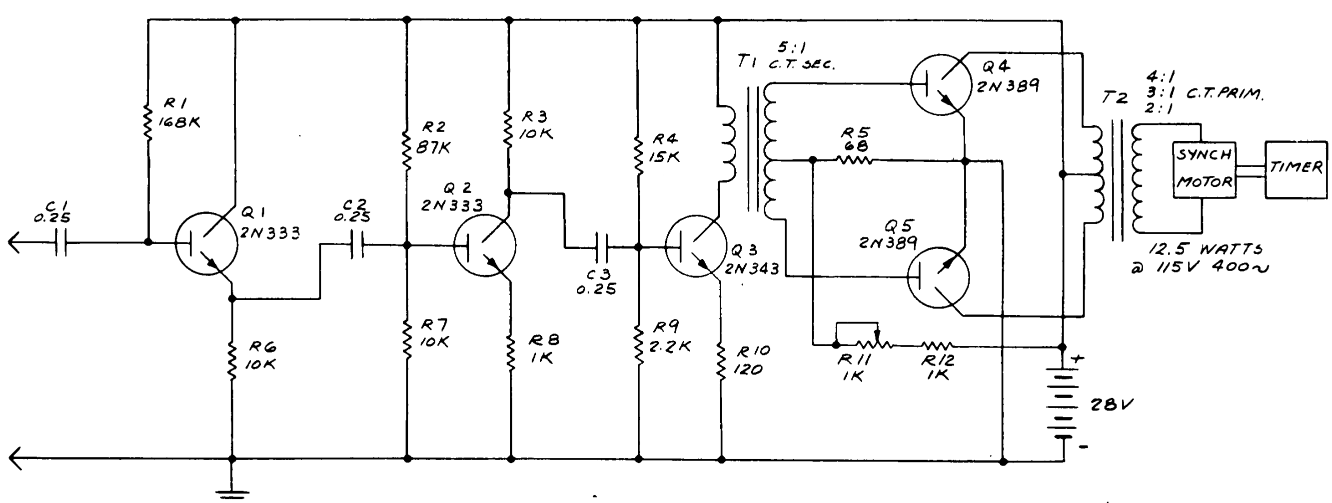

NEXT ASSY.	USED ON	NEXT ASSY. QTY REQ'D
APPLICATION		

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UNLESS OTHERWISE SPECIFIED—DIMENSIONS ARE IN INCHES
TOLERANCES ON: DEC. DIMS. ± FRAC DIM ± ANGULAR DIMS. ±

MATERIAL:

HEAT TREATMENT:

FINISH NO.

DWN Kelley DATE 4-4-58
CHKD ____ DATE ____
APPROVED MATLS ____ DATE ____
ENGRG ____ DATE ____
MFG ____ DATE ____
____ DATE ____

NAME: SCHEMATIC
TIMING AMPLIFIER
(AR 5)

SCALE: — WT. ACT. LBS.

FAIRCHILD CAMERA AND INSTRUMENT

DRAWING NUMBER 951SD3

IDI NO 1080

FCI-1084

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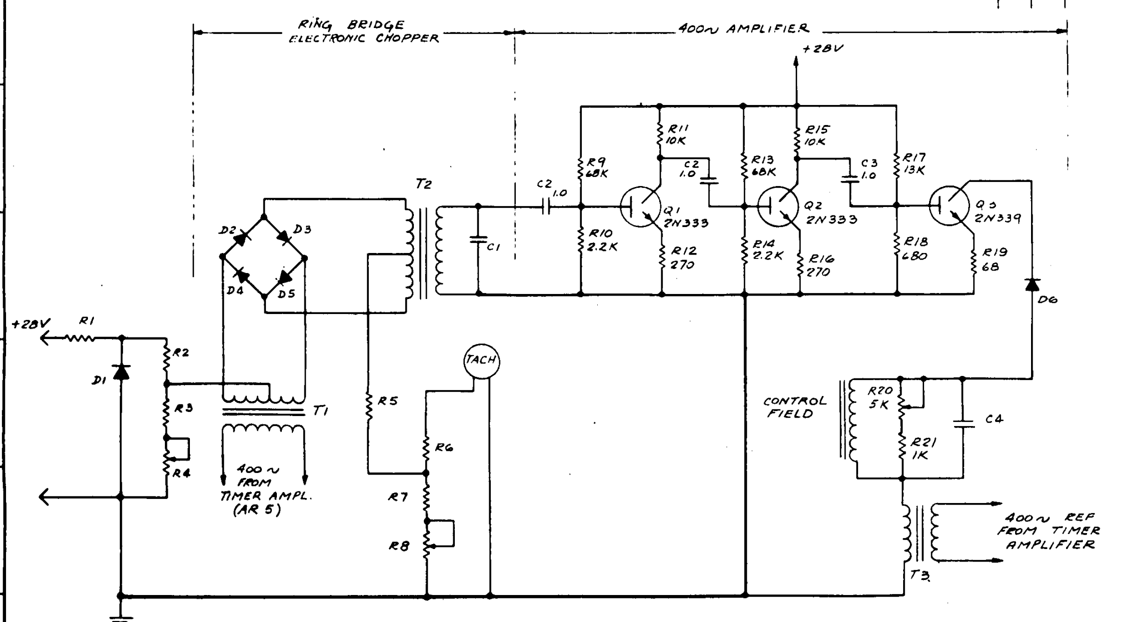

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NOTE.
ALL RESISTOR VALUES IN OHMS
ALL CAPACITOR VALUES IN MICROFARADS

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UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

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HEAT TREATMENT

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MATLS. ____ DATE ____
ENGRG. ____ DATE ____
MFG. ____ DATE ____

NAME:
SCHEMATIC,
VELOCITY SERVO
AMPLIFIER
(AR 4)

SCALE: WT. ACT. LBS.

NEXT ASSY. | USED ON
APPLICATION

FAIRCHILD
CAMERA AND INSTRUMENT

DRAWING NUMBER
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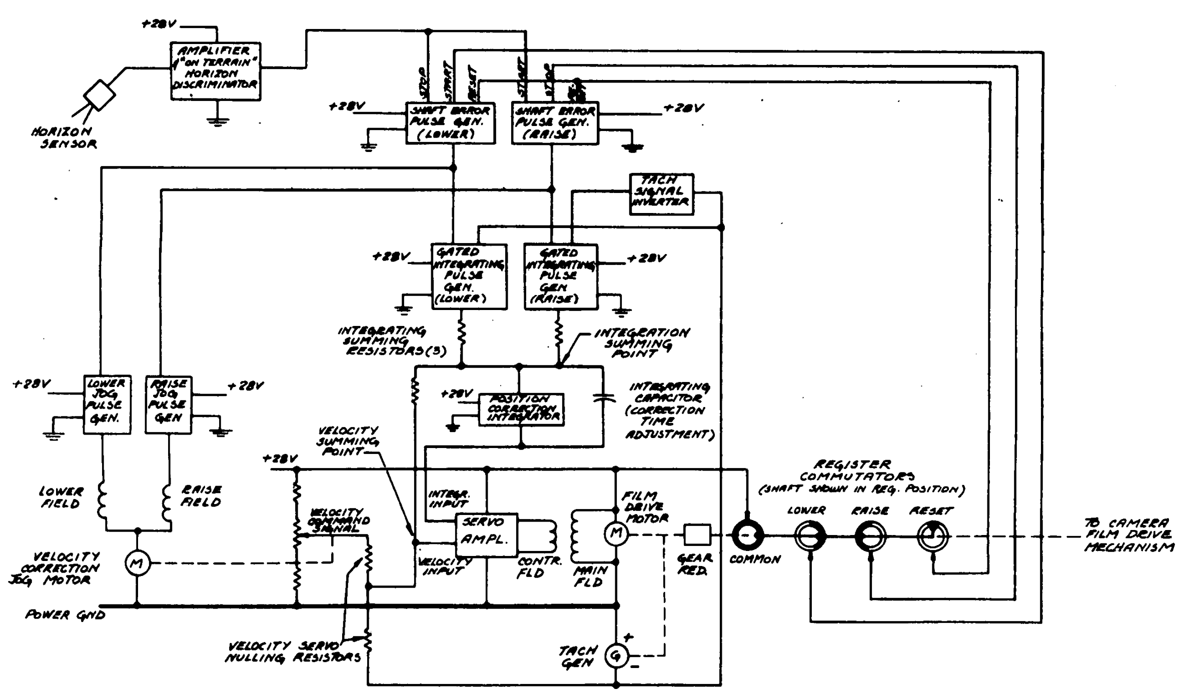

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DWN	4-20-65
FAIRCHILD CAMERA AND INSTRUMENT CORPORATION, ROBBINS LANE, SYOSSET, L. I., NEW YORK	
DRAWING NUMBER	951SD8

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Approved For Release 2009/06/15 : CIA-RDP74B00752R000100260001-7

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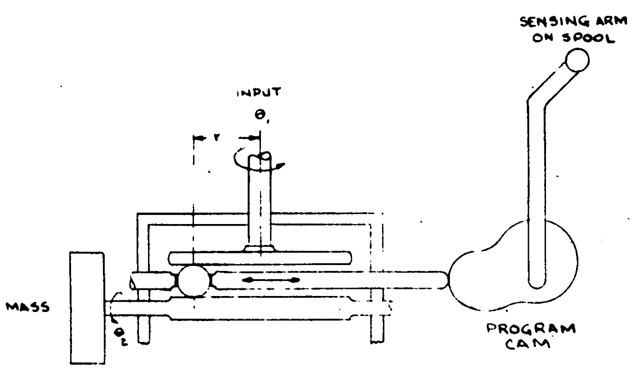

OUTPUT ROTATION
CHANGES AS r SHIFTS
TO RIGHT OF INPUT CENTER

BALL INTEGRATOR

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HEAT TREATMENT	APPROVED: MATLS. DATE; ENGRG. DATE; MFG. DATE; DATE		DRAWING NUMBER 951 L19
FINISH NO		SCALE — / WT. ACT. LBS.	

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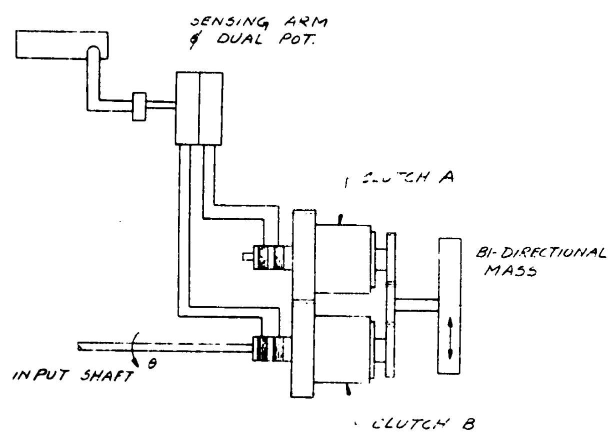

HYSTERESIS CLUTCH

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TOLERANCES: TWO PLACE DECS. ± .02 THREE PLACE DECS. ± .005; ANGULAR DIMS. ± 1° 00'

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CHKD ____ DATE ____
HEAT TREATMENT.
FINISH NO.
APPROVED MATLS. ____ DATE ____
ENGRG. ____ DATE ____
MFG. ____ DATE ____
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NAME: HYSTERESIS CLUTCH

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SCALE — | WT. ACT. LBS.

FAIRCHILD CAMERA AND INSTRUMENT CORPORATION

DRAWING NUMBER 951L20

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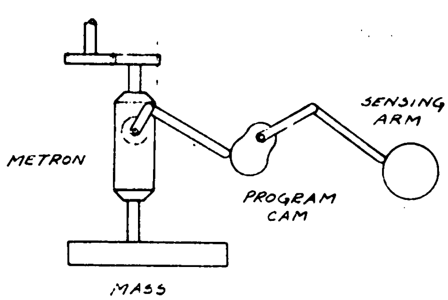

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MATERIAL

DWN. H.D DATE 4-4-58
CHKD DATE

HEAT TREATMENT

FINISH NO

APPROVED: MATLS. DATE / ENGRG. DATE / MFG. DATE / DATE

NAME: METRON SYSTEM

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SCALE. — WT. ACT. LBS.

FAIRCHILD CAMERA AND INSTRUMENT

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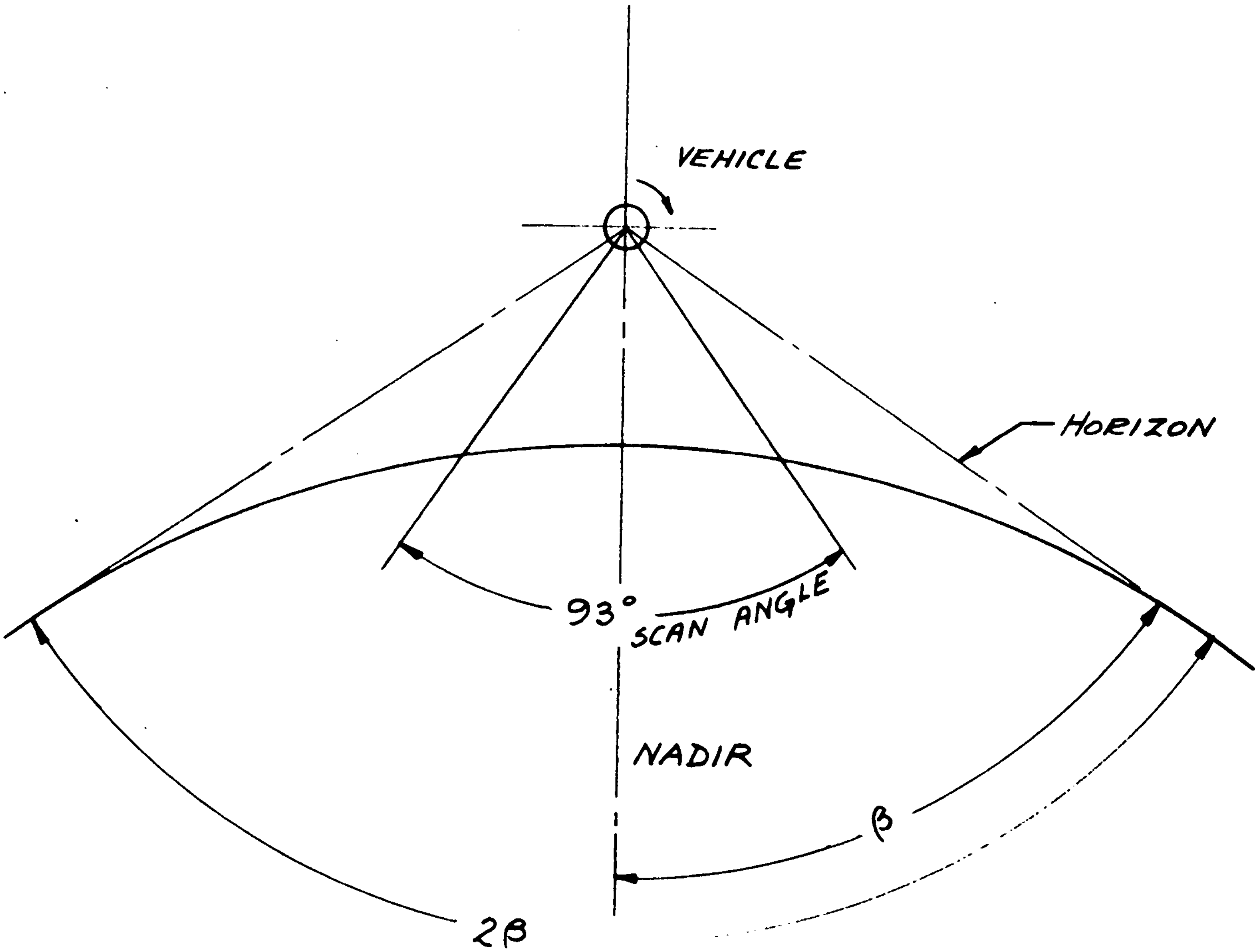

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FAIRCHILD
CAMERA AND INSTRUMENT
CORPORATION

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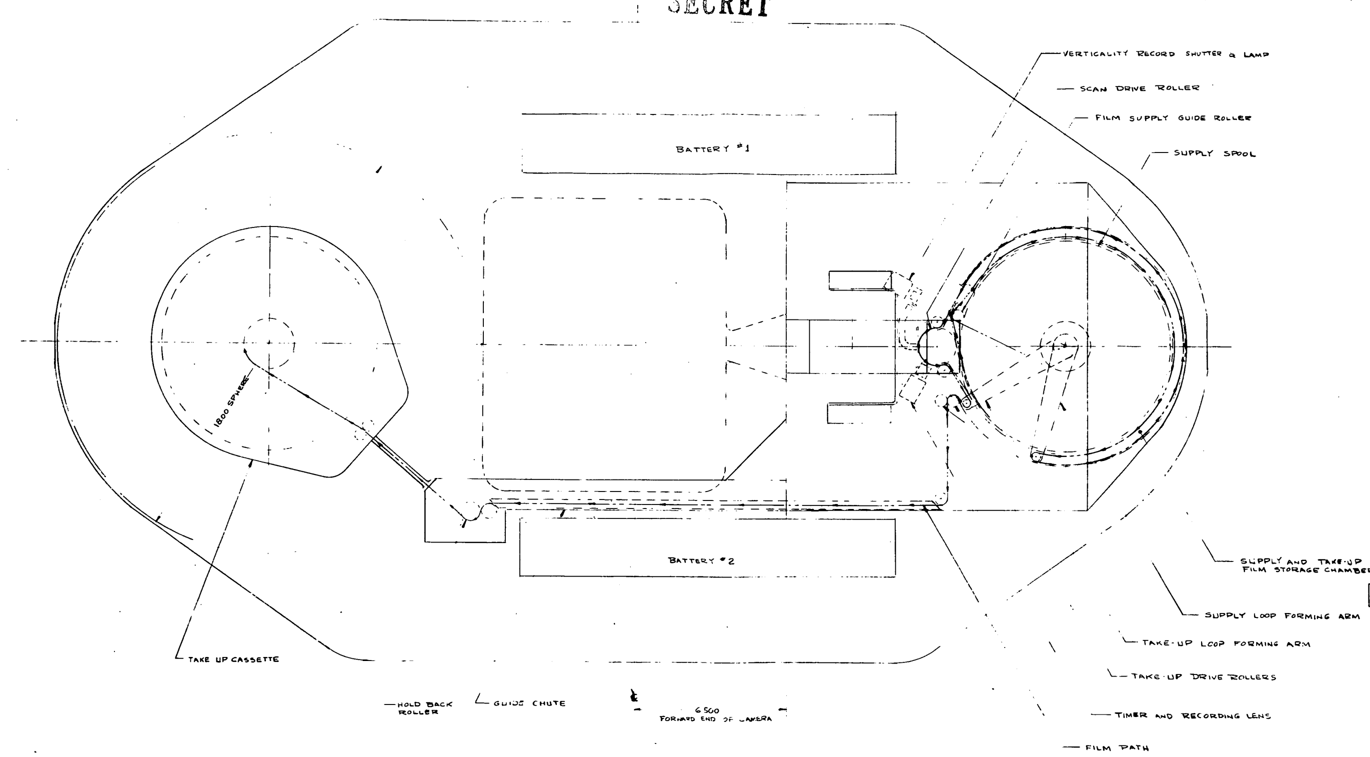

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REVISIONS	ZONE / SYM. / DESCRIPTION / E.C.N. NO. / DATE / APPROVAL
APPLICATION	NEXT ASSY. / USED ON
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WT ACT	LBS
	FAIRCHILD CAMERA AND INSTRUMENT CORPORATION, ROBBINS LANE, SYOSSET L.I. NEW YORK
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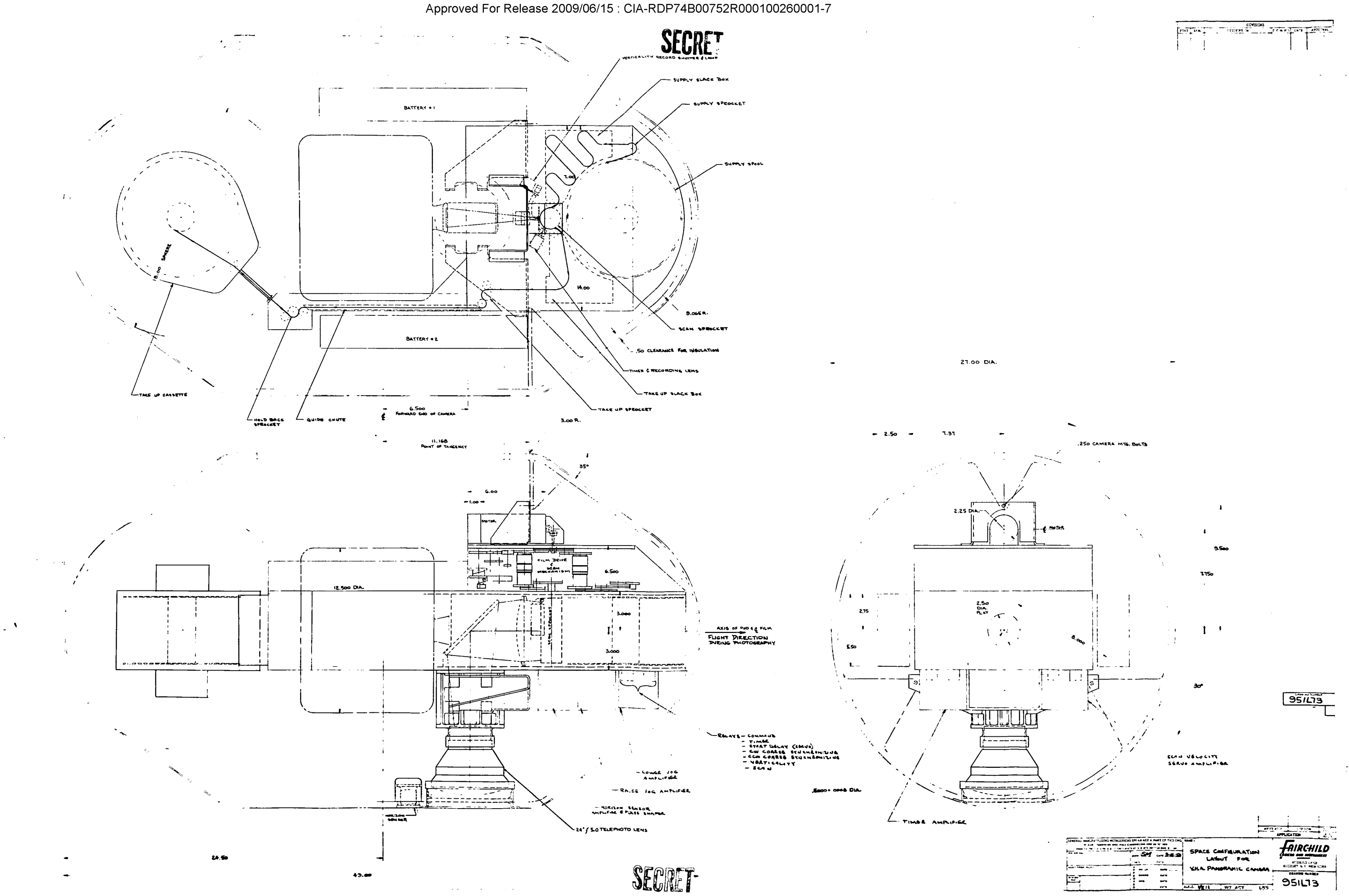

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